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ECONOMIC ANALYSIS OF DEMAND AND SUPPLY OF WATER IN ALBERTA MUNICIPALITIES

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Economic Analysis of Demand and Supply of Water in Alberta Municipalities submitted by Frantisek Hanus in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

This study is based on 1966 and 1967 Alberta waterworks pumpage and expenditure.data. The analysis is focused upon the identification and quantification of factors that affect the level of community and residential water use in particular, and the cost incurred in provision of water services. As an integral part of this study, a review of water use patterns and pricing practices of surveyed Alberta waterworks has been undertaken.

The primary data for this cross-sectional study (i.e., study related to a specific time) were gathered through a mail questionnaire sent to all Alberta municipalities. Additional information was obtained from various statistics periodically collected by the Alberta Department of Municipal Affairs, Dominion Bureau of Statistics, etc. Most of the data presented in this study are easily available to the individual planning agent without the necessity of undertaking complicated surveys.

The results of the demand analysis indicate that municipal consumers adjust their water use levels for differences in wealth, pricing methods, and for higher or lower prices whenever the consumers have a choice of how much water to use. When residential customers are subjected to flat or assessed flat rates, any increase in the rate tend to stimulate water use. This relationship is exactly opposite to that found in metered municipalities, where the size of a bill restrains water use.

In a multiple regression analysis of waterworks expenditure data, it has been clearly demonstrated that economies of scale are presented in the industry. This means that consolidation of small scale waterworks may be financially advantageous, providing that geographical and political factors are taken into consideration.

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SCOPE AND ORGANIZATION OF THE STUDY

Introduction

The importance of providing urban and rural communities with adequate supplies of clean, disease free, piped water has been recognized not only by modern society; Romans enjoyed services of their famous aqueducts built over two thousand years ago. In the North American context, the main impetus to the building and expansion of municipal waterworks was provided by the need to control fires, to keep the summer dust on the streets under control, and the conviction that polluted drinking water was the source of diseases such as cholera and typhoid fever.[1] This basic role of waterworks has also been expanded to provide enough good quality water for industries and for upgrading municipal landscapes, one of the important amenities to which modern society aspires. In addition, the existence of a water supply system makes possible the operation of a network of sewers -- a water-carrying system of collecting and disposing community sewage.

Society is forced to make allocative decisions because of the ever-present conditions of scarcity. The provision of water to the municipality requires large-scale investments which are almost wholly irreversible and involves the use of resources which might have been used for other and perhaps equally meritorious purposes. Thus, an analysis of water manage-

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[1] For more details on this issue, see: N.M. Blake, _Water for the Cities: A History of the Urban Water Supply Problem in the U.S._ (Syracuse: Syracuse University Press, 1956); and J.H. Mudrock, "75 Years of Too Cheap Water," _Journal of American Water Works Association_, Vol. 48, No. 8, pp. 925-930.

ment practices and water pricing methods would indicate whether and how much further investment in this basic, capital intensive municipal service is justified in terms of efficient allocation of the community's scarce resources.

Waterworks in Alberta have been developed primarily by municipalities themselves. Today, most waterworks are in municipal ownership. "Municipal ownership" in this case refers to ownership and operation of waterworks by city, town and village governments and "area municipalities" such as counties and municipal districts. For many communities municipal ownership was an economic necessity. The high capital investment required to establish a water supply system, and the absence of sufficient or timely private capital investment caused many communities to rely upon public credit for financing.[1] Another factor leading to government ownership of waterworks is the particularly close relationship between adequate water supplies and public health, sanitation, and fire protection.

The actual "consumption" of water in municipalities is estimated to be less than 10 percent of that diverted.[2] Furthermore, most of Alberta's larger population centres are located on rivers and lakes large enough to meet their water needs. However, most of the water returned to the stream flow is in the form of an effluent which is polluted by biological, or-

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[1] However, some exceptions can be found. In Calgary, a private firm, the Calgary Gas and Water Works Company, built a water supply system which was sold to the city for $ 3,750,000 in 1899, not too many years after the foundation of the waterworks. See: Municipal Manual of the City of Calgary, 1969, various pages.
In Camrose, Sherwood Park and Wetaskiwin, water is distributed by private utility companies.

[2] Hydrologists use the term "consumption" for water diverted permanently from the surface water by evaporation and other processes. A.H. Laycock, "Water," Canada: A Geographical Interpretation, edited by J. Warkentin. (Toronto: Methuen, 1968), p. 127.

ganic and inorganic contaminants. Thus, much greater amounts of water are needed to dilute and transport waste by-products, a direct result of the present way of life. The problem is particularly acute during low water flows in mid-summer or in winter, when there is only limited aeration and oxygen recharge of the warm (or ice covered) waters.[1] For this reason, municipalities in the province are required to install sewage treatment facilities so that the levels of discharged effluents does not exceed the self-purification capacity of the stream.

In summary, the physical supply of water for most of Alberta municipalities is adequate for the forseeable future and there is no crisis in this respect; but there is a continued need for planning the expansion of the municipal waterworks efficiently.

Economic Characteristics

Waterworks furnish a service to the public that is uniquely without competition from substitutes. A municipal waterworks is ordinarily a pure monopoly, except to the extent that industrial and sometimes residential consumers establish their own water supplies.[2] There are two main reasons for this: 1) there are often substantial economies of scale to be achieved by combined, not fragmented production and distribution of piped water

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[1] The City of Red Deer experimented with the blowing of air into the river streamflow underneath the sewage treatment plant in order to increase the oxygen content of the water.

[2] In Alberta, on the average, less than 2 percent of the municipal residents were not serviced by the municipal waterworks in 1967. Some municipalities, for example, Edmonton, prohibited industrial and commercial establishments located within the corporate limits of the municipality to set up their own water supplies.

and sewage treatment facilities; and 2) the natural sources of water supply should not be developed in piecemeal fashion.

Waterworks provide both water service to their customers and fire protection service to the general public. The beneficiaries of the latter service are the owners of property in the community. In order to provide public fire protection service, waterworks frequently must invest in more plant and storage capacity than would be required to supply service only to water users. These readiness-to-serve costs, fixed costs, are of importance mainly in small municipalities, where the fire protection capacity standards dominate local demands.

The relative distribution of receipts reveals that water sales revenues are the major source of a waterworks' income.[1] Thus, the need for more funds to continue and expend waterworks operations must ultimately be met through the waterworks' own water rates. However, the relatively large fixed investments are usually financed by issuing bonds or securing long-term loans. The rates, financing, or service of government-owned waterworks are determined by the communities they serve. Conventionally, the authority to set rates rests with the municipal council. Most communities have several types of rates that they impose on customers, among them, a fixed service charge per billing period, minimum charges, front-foot assessments, rates linked to the number of fixtures or water using appliances, installation charges, charges linked to lot size, and water and sewer rates that vary with the quantity of water used.

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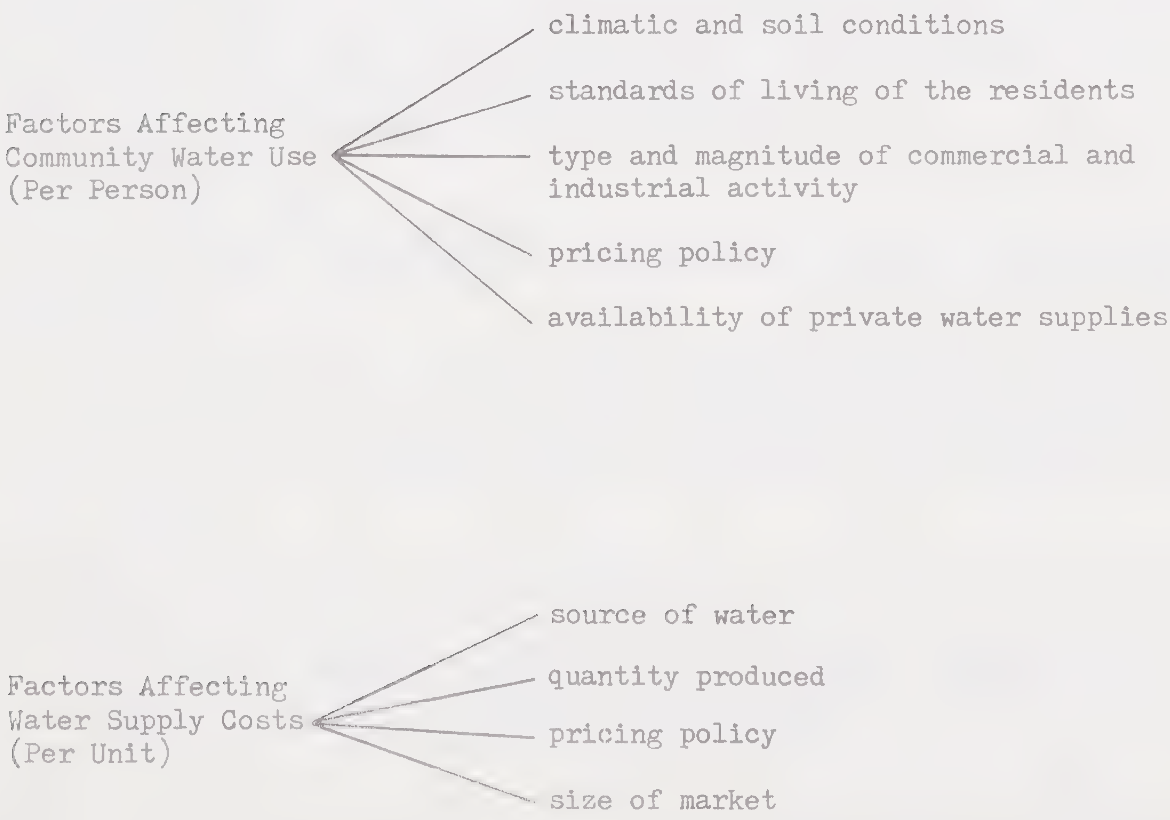
[1] Water sales revenue accounted for over 86 percent of the operating revenue. For more details, see Tables 11 and 18, pp. 30 and 40.

Scope and Objectives of the Study

The study focuses on the identification of factors that affect the level of community water use and the costs of supplying the water service (Figure 1). Some of these variables are less amenable to policy manipulation by the waterworks management (for example, level of evapotranspiration, household size, physical conditions affecting water supply). Other factors, such as pricing policies, may be varied by management with a view to ensuring the "optimal" or "most efficient" use of water and/or that of recouping costs of production.

FIGURE 1

SCHEMATIC PRESENTATION OF THE MAIN FACTORS INFLUENCING WATER USE AND WATER SUPPLY COSTS



The price system allocates resources most efficiently when demands are responsive to prices and when the costs of administering the system of prices are very low. For this reason, knowledge of demand and cost conditions facing the individual waterworks is needed in order to assess the consequences of different pricing principles.

In the analysis of community water demands (residential and non-residential), the main emphasis will be given to those factors which affect or determine the rate of water utilization or which are useful in predicting water demand.

A procedure for analyzing the costs of waterworks is intended to determine the industry supply function which can be used as a basis for establishing economically sound water rates. It is important to know how marginal cost changes as output is expended for establishing rational water rates.

This study is one of economic demand for water. Water utilization by consumers is seen as a function of both the relative price of water and the ability of the consumer to pay for it; that is, each consumer has a unique economic demand for water, and within certain limits, a choice of how much water to use.

Briefly then, the objective of this study is to obtain the following information:

1) An estimate of the responsivness of water consumption to changes in price -- in technical terms, an estimate of the elasticity of demand.
2) Cost relations in water supply.
3) A survey of present pricing practices, financial returns, and water use patterns in Alberta municipalities.

Information on rates, cost estimates and usage data from municipal records, government statistics, etc., are not readily available and had to be collected from many sources. A survey of municipal waterworks was a principal information source, supplemented by financial records as published by the Alberta Department of Municipal Affairs.

Organization of the Study

The description of the study area is given in the next section. Data collection is described in the final section of this chapter.

Water use patterns observed in Alberta municipalities, pricing methods and financial returns of Alberta waterworks are the main topics of Chapter II. Empirical findings of previous studies regarding the factors affecting community water use, and structural relationship of residential and community water demands are presented in Chapter III, which also includes the results of fitting estimating equations to sample data employing the method of least squares.

In Chapter IV pricing principles and practices are discussed first, and then, the derived cost function is evaluated in terms of principles stated earlier.

The final chapter summarizes the findings and makes some suggestions for improving our understanding of this topic through further research.

The Study Area

The Province of Alberta occupies 661,188 square kilometers (255,285 square miles); 97 percent being land and the balance fresh water. The province extends 1,216 kilometers from north to south and varies 293 to

650 kilometers east and west. Alberta has the most varied landscape of any Canadian province. There are the Rocky Mountain ranges, the foothills, the tall and short grass prairies, the parklands, the rocky Canadian Shield and vast forests.

Considering the extent of Alberta and its geographic location, variability of climate is to be expected. Latitude contributes to temperate summers and cold winters, and the continental interior location accentuates the seasonal temperature range and limits precipitation. The range of temperatures between the warmest and coldest months varies from about 7°C (45°F) in the southwest to 24°C and 27°C (75 and 80°F) in the far northern section of the province. The southeast part of Alberta has an average annual precipitation of about 300 mm and also has high evapotranspiration rates[1] caused by frequent hot dry winds. The west central part of the province has an annual precipitation of approximately 500 mm and lower evapotranspiration rates. In the extreme north, as in the south, precipitation is about 300 mm per year, but temperatures are much cooler and consequently, evapotranspiration rates are low. About 70 percent of the annual precipitation falls in the April-September half of the year. The average frost free period is over 120 days in the lowlands of southeastern Alberta and gradually decreases to 60 to 70 frost free days in the northern Peace River Valley.

A little over one million of Alberta's population lived in 315 municipalities in 1967; that is more than 70 percent of the total provincial

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[1] The combined evaporation from the soil surface and transpiration from plants, called evapotranspiration, represents the transport of water back to the atmosphere. For further details on measurements of evapotranspiration, see: C.W. Thornthwaite, "An Approach Toward a Rational Classification of Climate," Geographic Review, Vol. 38, (1948), pp. 55-94.

population. The distribution of Alberta's population over the last 70 years is shown in Figure 2. Even though only 78.1 percent of municipalities had waterworks, the vast majority of municipal residents (98.2 percent) enjoyed tapped water in 1967. This relative discrepancy is caused by the inflated total number of municipalities which includes summer villages with only seasonal residence, and some unincorporated places, counties, etc. The spatial distribution of municipalities, waterworks and population served is shown in Table 1.

The primary sources of water for the largest Alberta centres were rivers originating in the mountain areas of the province. However, the majority of smaller municipalities, including the city of Medicine Hat, were utilizing underground sources of water. Lakes and reservoirs provided

TABLE 1

WATERWORKS IN ALBERTA, BY REGION, 1967

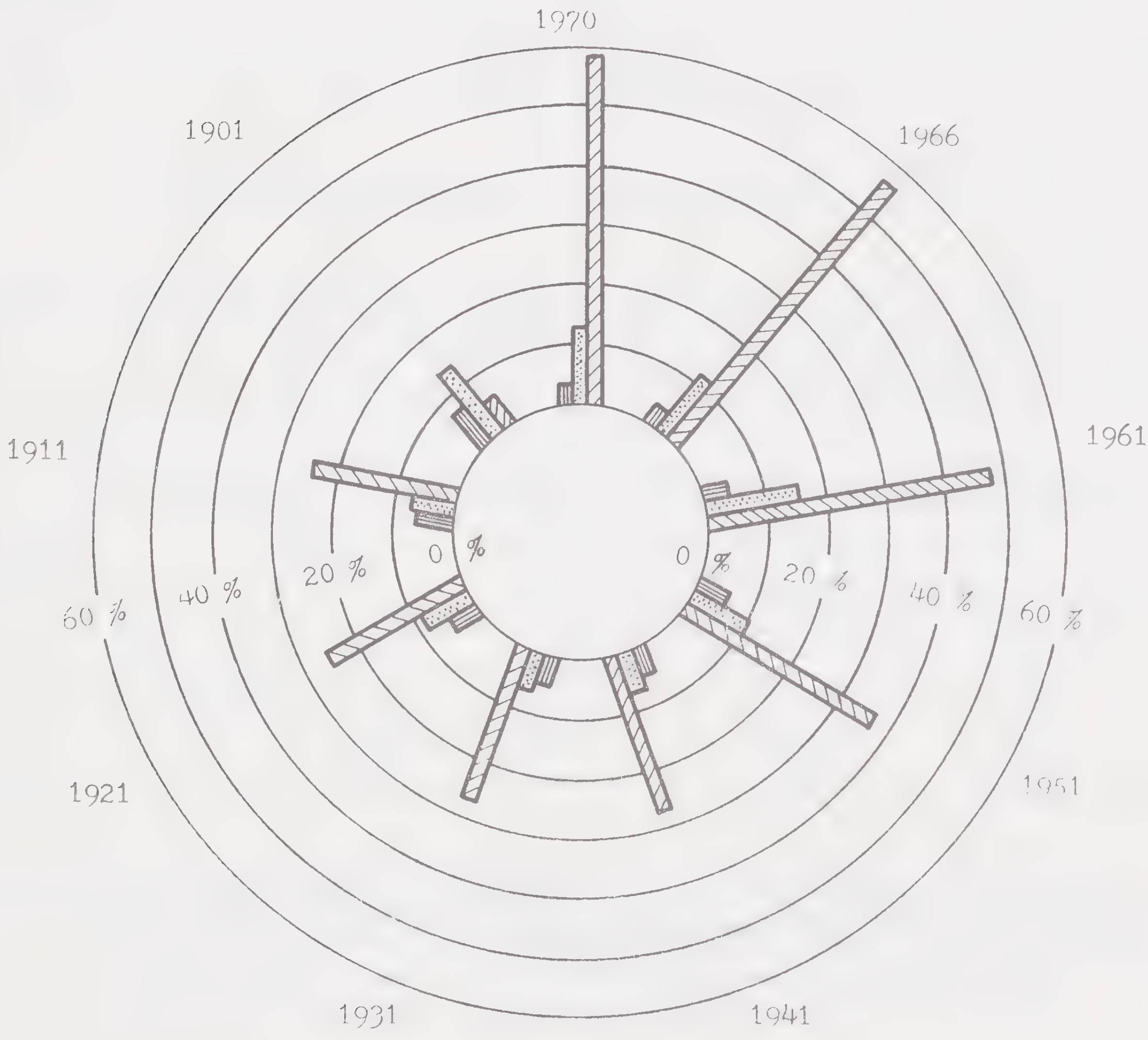
Alberta Region	Municipalities		Municipal Population	
	Total	Served by Waterworks	Total	Percentage Served by Waterworks
Southern	43	42	104,200	98.68
S.W. Central	50	44	386,692	99.53
S.E. Central	36	28	26,050	90.40
N. Central	110	74	505,642	98.22
Northern	76	58	73,909	93.76
All Municipalities	315[a]	246	1,096,493	98.24

[a] Including 29 summer villages, 30 unincorporated places, 6 counties and municipal districts, and 3 National Parks' town sites.

FIGURE 2

PERCENTAGE DISTRIBUTION OF POPULATION

IN ALBERTA'S MUNICIPALITIES (1901 - 1970)



Legend:

- Cities
- Towns
- Villages

water only to a small number of municipalities.[1]

Some municipalities in the southern part of the province depend upon irrigation systems for their water needs. Since the irrigation canals carry water only in the growing season, municipalities either have to build reservoirs or utilize underground water during the winter seasons. For a more detailed breakdown of waterworks by primary source of water and population served, see Table 2.

TABLE 2

WATERWORKS IN ALBERTA, BY PRIMARY SOURCE OF WATER, 1967

Primary Source of Water	Waterworks		Population Served	
	Total	Percentage of All Waterworks	Total	Percentage of All Population
Wells	137	55.70	111,149	10.32
Rivers	51	20.75	914,863	84.93
Reservoirs	22	8.94	19,075	1.77
Irrigation System	15	6.09	12,167	1.13
Lakes	15	6.09	15,644	1.45
Other	6	2.43	4,266	0.40
All Waterworks	246	100.00	1,077,164	100.00

Source: Alberta Department of Health. A Survey of Water and Sewage Systems in Alberta. Edmonton: Environmental Health Service Division, 1968; Alberta Department of Municipal Affairs. Annual Report, 1968. Edmonton: Department of Municipal Affairs, 1968.

[1] There is a significant difference in utilizing rivers and lakes (or reservoirs) with regard to pollution abatement. Rivers are unidirectional and pollution at one point is carried off toward the next downstream point. Water in lakes, on the other hand, do not mix readily; thus, communities located on lakes tend to pollute mainly themselves instead of their downstream neighbours.

Data Acquisition

The primary data for this cross-sectional study (i.e., study related to a specific time) were gathered through a mail questionnaire sent to all waterworks throughout the Province of Alberta during the summer months of 1968. Additional information was obtained from various statistics collected by the Alberta Department of Municipal Affairs, Alberta Department of Health, and Statistics Canada. This study relates to the years 1966 and 1967.

Most of the data obtained from the mail survey are generated in the course of ordinary municipal administrative activities. The individual waterworks offices were asked to give the following information:

1) Source(s) of water for the municipality.
2) Waterworks annual pumpage data.
3) Distribution of the gross pumpage among the community's water users.
4) Quantities of water sold to the customers outside the corporate limits of the municipality.
5) Number of customers served by the waterworks and connected to the community sewer system.
6) Number of households, commercial and industrial establishments not served by the waterworks and/or not connected to the community sewer system.
7) Water and sewage rates applicable during the survey.
8) Assessment of the adequacy of the existing waterworks.

Information regarding number and regional distribution of municipalities throughout the province, municipal population, building and land assessment values, number and type of dwellings, waterworks revenues and

expenditures, and precipitation was obtained from statistics collected by the different government institutions.

It is important to note that most of the data presented in this study are easily available to the individual planning agent without the necessity of undertaking complicated surveys. The utility of models which provide good statistical estimates is decreased if the information required is difficult to obtain.

CHAPTER II

WATER UTILIZATION, WATER RATES, AND WATERWORKS FINANCIAL RETURNS: EMPIRICAL EVIDENCE

Response to Municipal Water Survey

In 1967, there were 246 waterworks serving 1,077,164 people in Alberta. Annual gross pumpage data were received from 165 waterworks (i.e., a response rate of 67 percent) which provided water service to 1,032,531 Albertans (i.e., 96 percent of all municipal population served by waterworks). The reported annual pumpage accounts for 96 percent of the total estimated pumpage by all Alberta waterworks.[1] A more detailed breakdown of the response by region and primary source of water is given in Tables 3 and 4, respectively. The reader should be aware of pumpage data limitations, since not all waterworks measure the amount of water produced accurately.[2] In both tables the striking diversity among pumpage data is caused by uneven regional distribution of large urban centres and industries. Furthermore, Alberta's two largest cities, Calgary and Edmonton, drew their water from rivers.

The main components of municipal water demand are residential, commercial-industrial, and other uses.[3] Table 5 presents the relative

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[1] The estimate of the total waterworks pumpage is based on the weighted pumpages per person by region and primary source of water.

[2] This is especially true when a municipality utilizes several sources of water and/or when water produced is not metered to the users.

[3] Other uses include water provision for fire protection, street cleaning, irrigation of municipal parks, and agricultural uses. The latter are of importance in small rural communities.

TABLE 3

WATERWORKS REPORTING PUMPAGE ESTIMATES, BY REGION, ALBERTA, 1967

Alberta Region	Waterworks		Population		Annual Gross Pumpage[a]	
	Waterworks Reporting	Response Rate Percent	Served by Reporting Waterworks	Response Rate Percent	Gross Pumpage $m^3/Yr.$	Percentage of All Reporting Waterworks
Southern	31	73.81	93,684	91.11	25,004,217	13.95
S.W. Central	25	56.82	375,114	97.47	78,432,068	43.76
S.E. Central	16	57.14	15,776	67.00	1,420,268	0.79
N. Central	48	64.86	490,585	98.78	68,780,380	38.37
Northern	45	77.59	57,372	82.79	5,576,353	3.13
Waterworks Reporting	165	67.07	1,032,531	95.86	179,212,605	96.32[b]

[a] Average of two consecutive years 1966-1967.

[b] Annual Gross Pumpage by Reporting Waterworks is 96.32 percent of the estimated total gross pumpage by all Alberta waterworks.

TABLE 4

WATERWORKS REPORTING PUMPAGE ESTIMATES, BY PRIMARY SOURCE OF WATER, ALBERTA, 1967

Primary Source of Water	Waterworks		Population		Annual Gross Pumpage[a]	
	Waterworks Reporting	Response Rate Percent	Served by Reporting Waterworks	Response Rate Percent	Gross Pumpage m^3/Yr.	Percentage of All Reporting Waterworks
Wells	82	59.85	85,653	77.06	8,626,533	4.81
Rivers	41	80.39	904,593	98.88	165,416,919	92.30
Reservoirs	19	86.36	16,611	87.08	1,369,425	0.76
Irrigation System	13	86.67	11,650	95.75	2,212,652	1.23
Lakes	6	40.00	10,838	69.28	1,213,128	0.68
Others	4	66.67	3,186	74.68	373,948	0.22
Waterworks Reporting	165	67.07	1,032,531	95.86	179,212,605	96.32[b]

[a] Average of two consecutive years 1966-1967.

[b] Annual Gross Pumpage by Reporting Waterworks is 96.32 percent of the estimated total gross pumpage by all Alberta waterworks.

TABLE 5

DISTRIBUTION OF GROSS PUMPAGE FOR REPORTING WATERWORKS, ALBERTA, 1966-1967

Size of Waterworks	Waterworks Reporting	Average Population Served	Average Gross Pumpage	Distribution of Gross Pumpage					
				Residential Use		Commercial and Industrial Use		Public and Other Uses[a]	
			m^3/Yr.	m^3/Yr.	Percent[b]	m^3/Yr.	Percent[b]	m^3/Yr.	Percent[b]
Gross Pumpage >1 mil. m^3/yr.	7	114,004	20,196,695	11,033,285	54.63	7,146,527	35.38	2,016,883	9.99
Gross Pumpage >100,000 m^3/yr.	30	2,989	311,288	225,657	72.49	55,887	17.95	29,744	9.56
Gross Pumpage <100,000 m^3/yr.	30	544	31,881	21,116	66.23	7,030	22.05	3,735	11.71
Waterworks Reporting Distribution	67	13,493	2,263,760	1,263,226	55.80	774,824	34.23	225,710	9.97

[a] Including fire protection, street cleaning, irrigation of public parks, and agricultural uses.

[b] Percent of Gross Pumpage.

importance of the three classes of use for 67 municipal waterworks reporting pumpage information.[1] The data in this table show that with the increasing size of waterworks, the relative importance of water supplied to residential users decreases and the relative importance of water supplied to commercial and industrial customers increases. However, little variation can be found in water supplied for public and other uses.

Effect of Metering

Community water demand is greatly affected not only by absolute numbers of customers in each user class, but also by the mode of pricing, i.e., whether customers are metered and pay in proportion to the quantity of water taken, or pay a flat rate only. The comparison is not between metered and unmetered water use *per se*, but among marginal water prices to users ranging from zero (for unmetered water use) to some positive levels per unit of water taken, which are the result of pricing mode. In Tables 6 and 7 empirical evidence of some of the differences found in Alberta municipalities is presented. The main features observed are:

1) the proportion of waterworks reporting pumpage estimates is far greater in metered municipalities,
2) the proportion of metering is greater in larger municipalities,
3) there are substantial deviations in water utilization by type of use between metered and flat rate pricing municipalities within the same size of waterworks.

The differences between metered and flat rate pricing municipalities

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[1] Even though 165 municipal waterworks reported annual gross pumpage data, only 67 gave the required breakdown by class of use.

TABLE 6

GROSS PUMPAGE BY TYPE OF USE IN METERED MUNICIPALITIES, ALBERTA, 1966-1967

Size of Waterworks	Waterworks Reporting	Average Population Served	Average Gross Pumpage	Water Use per Person	Proportion of Gross Pumpage in Percent: Residential Use	Commercial and Industrial Use	Public and Other Uses
			Cubic Meters per Year		Percent		
Gross Pumpage >1 mil. m^3/yr.	4	114,047	1,610,529	141.216	41.76	48.27	9.97
Gross Pumpage >100,000 m^3/yr.	23	3,221	303,915	94.354	74.30	15.50	10.21
Gross Pumpage <100,000 m^3/yr.	23	583	33,722	57.842	64.81	23.07	12.12
Waterworks Reporting	50	10,874	1,443,736	132.769	45.16	44.82	10.02

TABLE 7

GROSS PUMPAGE BY TYPE OF USE IN FLAT RATE PRICING MUNICIPALITIES, ALBERTA, 1966-1967

Size of Waterworks	Waterworks Reporting	Average Population Served	Average Gross Pumpage	Water Use per Person	Proportion of Gross Pumpage in Percent		
					Residential Use	Commercial and Industrial Use	Public and Other Uses
			Cubic Meters per Year		Percent		
Gross Pumpage >1 mil. m^3/yr.	3	113,947	25,651,937	225.121	65.40	24.60	10.00
Gross Pumpage >100,000 m^3/yr.	7	2,225	335,515	150.793	67.14	25.25	7.61
Gross Pumpage <100,000 m^3/yr.	7	418	25,833	61.801	72.33	17.67	10.00
Waterworks Reporting	17	21,197	4,675,598	220.578	65.47	24.61	9.93

are brought out more clearly by the following tabulation of residential consumption data per person (Table 8). There are three main points to be made with respect to residential use: 1) water use per person is much lower when water is metered, compared among municipalities of similar size; 2) these differences tend to increase with community size; 3) water use per person is lower in smaller communities.

Large urban centres tend to attract more commercial and industrial establishments than their smaller counterparts. Thus, quantities of water taken by these customers vary widely with the size of municipality (see Table 9). This table, however, does not reflect the actual impact of metering, since all or at least the larger commercial and industrial customers are metered even in otherwise flat rate pricing municipalities.

Residential Water Pricing Policies

Levying charges for public water service is not an innovational practice. As early as 97 A.D., the newly appointed administrator of waterworks in Imperial Rome began to charge for what had been a privilege.[1] Water meters in a relatively practical form first made their appearance on this continent at the end of the Nineteenth Century.[2]

Analysis of waterworks pricing policies reveals that both major pricing methods, i.e., metered and flat rate pricing, were widespread throughout the province. The operational characteristic of a flat rate

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[1] P.P. Azpurua, et al, "New Water Rates for Caracas," Journal of American Water Works Association, Vol. 60, No. 7, (1968), p. 774.

[2] A. Hazen, Metered Rates for Water Works. (New York: John Wiley & Sons, Inc., 1918), p. 1.

TABLE 8

RESIDENTIAL WATER CONSUMPTION PER PERSON IN REPORTING MUNICIPALITIES,[a] ALBERTA, 1966-1967

Size of Waterworks	Metered Pricing				Flat-Rate Pricing			
	Waterworks Reporting	Average Population Served	Residential Consumption m^3/Person/Yr.	Residential Consumption CV[b]	Waterworks Reporting	Average Population Served	Residential Consumption m^3/Person/Yr.	Residential Consumption CV[b]
Gross Pumpage >1 mil. m^3/yr.	4	114,047	70.060	32.85	3	113,947	227.687	87.70
Gross Pumpage >100,000 m^3/yr.	23	3,221	81.679	31.51	7	2,225	114.973	28.25
Gross Pumpage <100,000 m^3/yr.	23	583	39.820	33.26	7	418	52.392	31.76
Waterworks Reporting	50	10,874	61.069	46.96	17	21,197	109.095	89.54

[a] Residential water consumption per person serviced by waterworks.

[b] CV is the coefficient of variation (CV = std. deviation/mean x 100).

TABLE 9

COMMERCIAL AND INDUSTRIAL WATER USE PER PERSON,[a] ALBERTA, 1966-1967

Size of Waterworks	Metered Pricing				Flat-Rate Pricing			
	Waterworks Reporting	Average Population Served	Comm. & Industrial Use		Waterworks Reporting	Average Population Served	Comm. & Industrial Use	
			m^3/Person/Yr.	CV[b]			m^3/Person/Yr.	CV[b]
Gross Pumpage >1 mil. m^3/yr.	4	114,047	61.404	35.31	3	113,947	62.085	7.38
Gross Pumpage >100,000 m^3/yr.	23	3,221	19.199	64.11	7	2,225	33.177	56.44
Gross Pumpage <100,000 m^3/yr.	23	583	12.506	62.15	7	418	11.182	84.60
Waterworks Reporting	50	10,874	19.497	87.38	17	21,197	29.222	78.45

[a] Commercial and industrial water use per person residing in the municipality.

[b] CV is the coefficient of variation.

is that it is an "access charge" or capacity rate as well as a zero "commodity charge". For the user the first gallon of water per month does have a high price, but subsequent water quantities taken cost him nothing. In the case of metered pricing, the charge is a "commodity charge"; the marginal price per gallon is always greater than zero. According to Figure 3, the 151 reporting waterworks seem to be fairly evenly divided in their preferences for a particular pricing method.

In Alberta's metered municipalities, the straight-line meter rate schedule[1] is very seldom used. Virtually all reported metered municipalities use a block meter rate schedule,[2] which includes a graduated minimum rate that increases as the size of the meter increases. (The customer's meter size is usually determined by the size of the pipe leading into his premises. Most residential customers have a 5/8 inch meter.) Basing the minimum rate on the size of the consumer's meter is intended to reflect differences in the waterworks' fixed costs of readiness-to-serve customers of different sizes.

Ninety-two percent of the metering waterworks allowed some base quantity of water with the minimum bill. Water consumption in excess of this quantity was charged at the "commodity" price which will be referred to as the variable or marginal price. Figure 4 shows the amounts of water allowed with the minimum bill per residential account per year.

Economies of scale appear to be reflected by the fact that minimum

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[1] A straight-line rate is a rate which charges the customer a constant dollar value per metered unit of water taken regardless of the quantity of water consumed.

[2] A block rate schedule refers to a rate schedule which provides a varying price per unit of water for successive blocks (or quantities of consumption). This type of rate schedule usually offers successively lower rates per unit of water in each block of water consumed.

FIGURE 3

PRICING METHODS OF RESIDENTIAL CUSTOMERS, ALBERTA, 1967

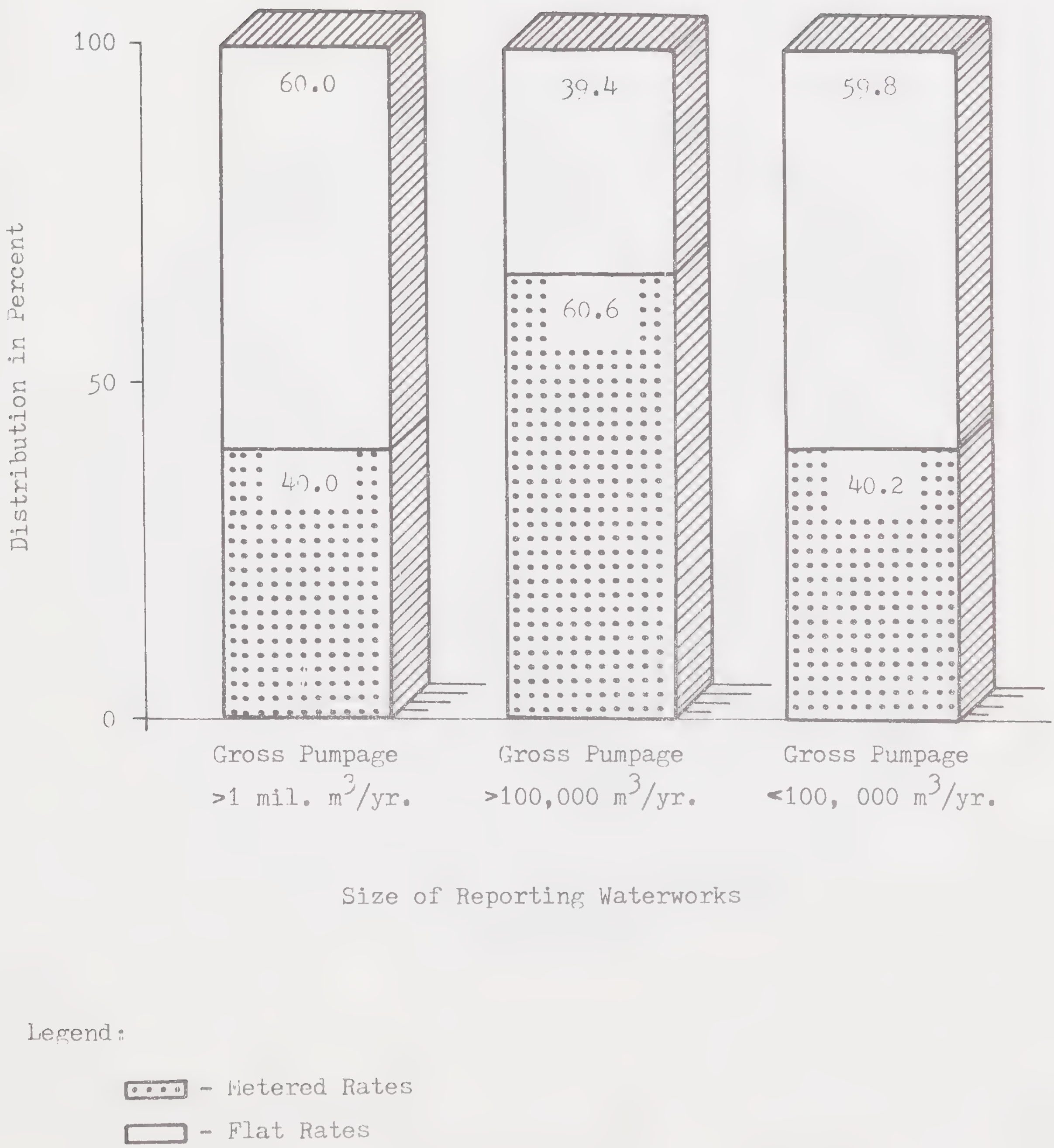
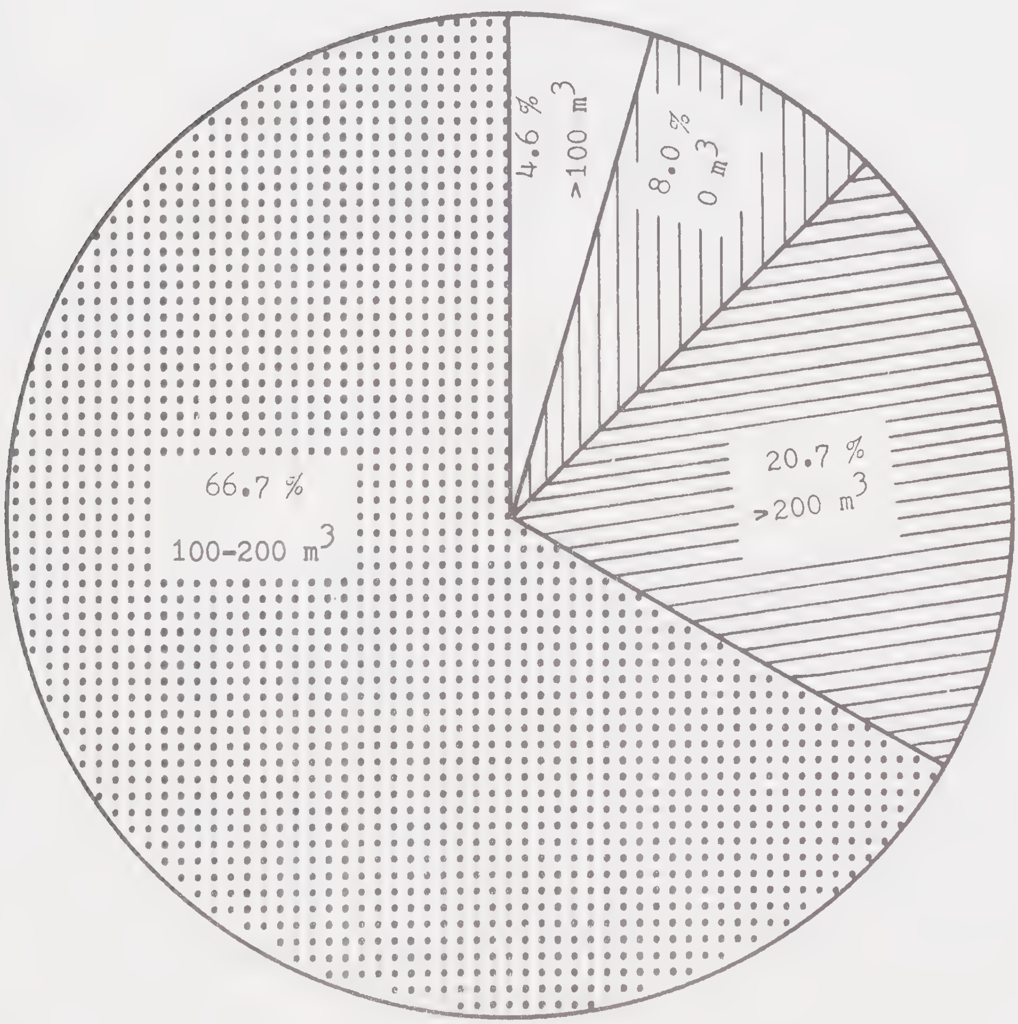


FIGURE 4

AMOUNTS OF WATER ALLOWED WITH A MINIMUM BILL PER RESIDENTIAL ACCOUNT

PER YEAR, ALBERTA, 1967

(All Reported Metered Municipalities = 100 Percent)



rates, variable rates, and flat rates of residential accounts are inversely related to the size of the waterworks. Variation in rates is also related to the differential cost of water drawn from wells, springs, or rivers; differential treatment practices and purification needs; and varied distribution expenses which depend on the density of the settlement within a community and need for pressure pumping. In Table 10 the variation in water rates with respect to waterworks size is shown.

The municipal water survey also revealed that some of the metered municipalities granted special summer rebates to their residential customers either in the form of reduced unit rates (up to 50 percent in the most frequently applied residential block), or by substantial increase in the base quantity under the minimum bill. However, in all cases the minimum bill remained unchanged. Apparently the rebate is intended to encourage "beautification".

Waterworks Financial Returns

Traditionally, waterworks revenues should be sufficient to provide for continued adequate service, that is, water revenues should cover operation expenses, debt service costs (interest charges and amortization), taxes, and the cost of normal extensions and improvements.[1] However, the analysis of financial data obtained from the 1966 and 1967 Municipal Annual Reports, published by the Alberta Department of Municipal Affairs, shows that some waterworks diverge significantly from the principles described above.

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[1] P.C. Mann, "New Focus in Water Supply Economics -- Urban Water Pricing," Journal of American Water Works Association, Vol. 62, No. 9, (1970), p. 534.

TABLE 10

RESIDENTIAL WATER RATES IN METERED AND FLAT RATE MUNICIPALITIES,

ALBERTA, 1966-1967

Size of Waterworks	Metered Pricing			Flat Rate Pricing	
	Waterworks Reporting	Minimum Annual Rate $/Resident Account/Yr.	Variable Rate[a] Cents/m^3	Waterworks Reporting	Flat Annual Rate $/Resident Account/Yr.
Gross Pumpage >1 mil. m^3/yr.	4	29.94	21.23	6	47.84
Gross Pumpage >100,000 m^3/yr.	37	40.38	22.95	24	45.94
Gross Pumpage <100,000 m^3/yr.	34	42.71	24.10	46	50.56
Waterworks Reporting	75	40.88	23.38	76	48.89

[a] Variable Rate in first block.

The relative distribution of receipts reveals that water sales revenues, i.e., revenues from water sales to residential, commercial, industrial, and other customers, are the major source of waterworks' income, especially for those serving small communities. Revenues generated from fire protection charges[1] and from other waterworks services constitute only a small proportion of a waterworks' operating revenues.

In many smaller municipalities, where water sales revenues and revenues received for other services[2] are insufficient to cover the waterworks' expenditures, transfers from general revenues (taxes) become an important source of waterworks revenues (see Tables 11 to 18). It should be noted that transfers from general revenues also include frontage charges and other special tax levies which are planned as a means of financing the provision of water. They are just another component of the multipart price differentiated in the manner in which they are levied.

The production of piped water involves a heavy initial outlay[3] and a relatively modest annual outlay for maintenance and operation.[4]

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[1] One of the reasons most of the waterworks go uncompensated or are undercompensated for public fire protection service is that these waterworks do not pay taxes (with the exception of a few in large urban centres) to the local governments. Thus, it is regarded a fair trade to exchange this exception from local taxes for the lack of compensation for public fire protection service.

[2] "Other services" provided by the waterworks include the provision of water to public buildings, public water fountains, irrigation of municipal parks, and street and sewer flushing, etc.

[3] In Ontario, new investment in municipal waterworks per additional person served was $ 337.05 (1967 dollars) during 1958-67. See: A.P. Grima, Residential Water Demand. (Toronto: University of Toronto Press, 1972), p. 20.

[4] In Alberta, the annual outlay per person served varied between $ 11.15 to $ 33.11 depending upon the community size and/or waterworks size. For further detailes see Tables 1 to 6, Appendix II.

TABLE 11

FINANCIAL RETURNS OF WATERWORKS REPORTING, BY REGION, ALBERTA, 1966

(Dollars per Year)

Alberta Region	Waterworks Reporting	Sales Revenue[a]	Other Revenue[b]	Operating Revenue[c]	Expenditure[d]	Operating Surplus or Deficit (-)[e]	Net Transfers from General Revenue Fund[f]
Southern	35	$ 1,535,555	$ 96,870	$ 1,632,425	$ 1,695,155	$ -62,730	$ 110,430
S.W. Central[1]	38	654,329	176,208	830,537	910,563	-80,026	151,982
S.E. Central	27	371,412	13,632	385,044	457,704	-72,660	106,194
N. Central[2]	56	541,073	92,590	633,663	920,903	-287,240	303,223
Northern	51	1,038,860	80,306	1,119,166	1,285,047	-165,881	280,674
Major Cities[3]	2	10,493,369	1,872,864	12,366,233	9,122,577	3,243,656	-948,345
Waterworks Reporting	209	$ 14,634,598	$ 2,332,470	$ 16,967,068	$ 14,391,949	$ 2,575,119	$ 4,158

Source: Department of Municipal Affairs. Annual Report 1966. Edmonton: Queen's Printer, 1968.

(continued)

TABLE 11 (continued)

Notes: [1] Excluding the City of Calgary.

[2] Excluding the City of Edmonton.

[3] This group includes Calgary and Edmonton.

[a] Revenues from water sales to residential, commercial, industrial and other customers.

[b] Revenue from Hydrant Rentals and Miscellaneous Revenue.

[c] Sales Revenue plus Other Revenue.

[d] In the case of several cities, transfers to the General Revenue Fund are excluded.

[e] Operating Revenue minus Expenditure.

[f] Transfers from the General Revenue Fund minus transfers to the General Revenue Fund. (A negative sign implies that the waterworks contributions to the Fund exceeded those received from that Fund.)

TABLE 12

FINANCIAL RETURNS OF WATERWORKS REPORTING, BY REGION, ALBERTA, 1967

(Dollars per Year)

Alberta Region	Waterworks Reporting	Sales Revenue[a]	Other Revenue[b]	Operating Revenue[c]	Expenditure[d]	Operating Surplus or Deficit (-)[e]	Net Transfers from General Revenue Fund[f]
Southern	35	$ 1,718,636	$ 56,764	$ 1,775,400	$ 1,812,300	$ -36,900	$ 120,288
S.W. Central[1]	38	732,583	136,467	869,050	982,523	-113,473	180,548
S.E. Central	27	416,340	8,694	425,034	465,912	-40,878	99,807
N. Central[2]	56	632,098	86,667	718,765	1,000,535	-281,770	312,614
Northern	51	1,236,597	75,697	1,312,294	1,509,090	-196,796	288,983
Major Cities[3]	2	11,489,461	1,760,542	13,250,003	8,890,154	4,359,849	-1,109,590
Waterworks Reporting	209	$ 16,225,715	$ 2,124,831	$ 18,350,546	$ 14,660,514	$ 3,690,032	$ -107,350

Source: Department of Municipal Affairs. Annual Report 1967. Edmonton: Queen's Printer, 1969.

Note: 1, 2, 3, a, b, c, d, e, f, see Table 11.

TABLE 13

STRUCTURE OF FINANCIAL RETURNS OF WATERWORKS REPORTING, BY REGION, ALBERTA, 1966

(Expenditures = 100)

Alberta Region	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)[a]
Southern	35	90.58	5.72	96.30	-3.70	6.52	2.82
S.W. Central	38	71.86	19.35	91.21	-8.79	16.69	7.90
S.E. Central	27	81.15	2.98	84.13	-15.87	23.20	7.33
N. Central	56	58.76	10.05	68.81	-31.19	32.93	1.74
Northern	51	80.84	6.25	87.09	-12.91	21.84	8.93
Major Cities	2	115.03	20.53	135.56	35.56	-10.39	25.17
Waterworks Reporting	209	101.69	16.20	117.89	17.89	0.03	17.92

[a] Operating Surplus or Deficit plus Net Transfers from General Revenue Fund.

TABLE 14

STRUCTURE OF FINANCIAL RETURNS OF WATERWORKS REPORTING, BY REGION, ALBERTA, 1967

(Expenditures = 100)

Alberta Region	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)[a]
Southern	35	94.83	3.13	97.96	-2.04	6.64	4.60
S.W. Central	38	74.56	13.89	88.45	-11.55	18.37	6.82
S.E. Central	27	89.36	1.87	91.23	-8.77	21.42	12.65
N. Central	56	63.18	8.66	71.84	-28.16	31.24	3.39
Northern	51	81.94	5.02	86.96	-13.04	19.15	6.11
Major Cities	2	129.24	19.80	149.04	49.04	-12.48	36.56
Waterworks Reporting	209	110.68	14.49	125.17	25.17	-0.73	24.44

[a] Operating Surplus or Deficit plus Net Transfers from General Revenue Fund.

The principal items of operating and maintenance costs are: 1) production costs depending on the amount of pumping required and the type of treatment necessary to render the water safe, potable and clear; 2) distribution system costs incurred in transporting the water from the treatment facility to the customer; and 3) service costs, which include administrative expenses associated with billing, establishing a customer in the system and other associated costs. Other expense items included in the waterworks' annual budget are debt interest, amortization, capital additions and/or improvements and an amount for local taxes.[1]

Another important statistic showing the financial situation of a waterworks is the operating surplus (or deficit) based upon the difference between the waterworks' operating revenue (i.e., sales and other revenues) and annual expenditure. In a case where the latter is greater, a transfer from the general taxation ensures the solvency of the waterworks. However, a transfer of funds to cover waterworks loss does not necessarily mean subsidization. Transfers might include frontage and other taxes earmarked to finance waterworks, and often are in lieu of specific payments for certain public uses (e.g., fire protection service, provision of water for public use, etc.).

From Tables 11 to 14, which indicate the structure of financial returns of most of Alberta municipal waterworks for two subsequent years, averaged by region, the following generalizations can be made:

1) water sales revenues constitute the major part of operating revenues;

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[1] Since only in a few larger urban centres waterworks expenses also included tax contributions, these amounts were excluded from the budget expenses for reason of homogeneity in this study.

2) over two-thirds of waterworks receive funds from general taxation to cover the operating costs;

3) only in the case of two largest municipalities did waterworks contribute more to the municipal revenue fund than they received from the general taxation;

4) on the average, waterworks operating revenues tend to increase faster over time than expenditures. This is mainly due to increases in water sales revenues rather than in revenues for other waterworks services.

The effect of community size upon the financial situation of the waterworks is demonstrated in Tables 15 to 18. The importance of large scale production is evident by the fact that waterworks serving a large number of users show operating surpluses and net contributions to the local tax revenue fund. Furthermore, only the largest group shows a slight decrease in expenditures between 1966 and 1967, while sales revenues, increased by almost 8.5 percent. The increase in sales revenues for the remaining waterworks varies from 8.8 percent to a little over 28 percent; the increase in expenditures, ranges from 4.5 percent to 31.5 percent per annum.

In summary, the data in Tables 11 to 18 show quite conclusively the impact of the individual revenue items upon the financial situation of a waterworks. Only in large communities are water sales revenues sufficient to cover the entire budget expenses; the smaller municipalities transfer relatively large sums from the general taxation to balance the waterworks' budget. In the following section the effect of scale measured in terms of pumpage and of the source of water on the financial situation of a waterworks will be presented.

TABLE 15

FINANCIAL RETURNS OF WATERWORKS REPORTING, BY POPULATION SIZE, ALBERTA, 1966

(Dollars per Year)

Population Size	Waterworks Reporting	Sales Revenue[a]	Other Revenue[b]	Operating Revenue[c]	Expenditure	Operating Surplus or Deficit (-)[e]	Net Transfers from General Revenue Fund[f]
>100,000	2	$ 9,937,633	$ 1,664,261	$ 11,601,894	$ 8,358,252	$ 3,243,642	$ -948,345
10,001-100,000	4	1,234,448	415,961	1,650,409	1,636,440	13,969	101,160
3,001-10,000	15	928,995	117,571	1,046,566	1,114,755	-68,189	142,860
1,001-3,000	47	1,521,625	88,499	1,610,124	1,814,388	-204,264	291,310
501-1,000	40	499,040	26,715	525,755	674,720	-148,965	165,515
<500	96	484,992	19,446	504,438	753,984	-249,546	242,250
Counties and Municipal Districts	5	27,865	17	27,882	39,410	-11,528	9,408
Waterworks Reporting	209	$ 14,634,598	$ 2,332,470	$ 16,967,068	$ 14,391,949	$ 2,575,119	$ 4,158

Source: Department of Municipal Affairs. Annual Report 1966. Edmonton: Queen's Printer, 1968.

Note: a, b, c, d, e, f, see Table 11.

TABLE 16

FINANCIAL RETURNS OF WATERWORKS REPORTING, BY POPULATION SIZE, ALBERTA, 1967

(Dollars per Year)

Population Size	Waterworks Reporting	Sales Revenue[a]	Other Revenue[b]	Operating Revenue[c]	Expenditure[d]	Operating Surplus or Deficit (-)[e]	Net Transfers from General Revenue Fund[f]
>100,000	2	$ 10,779,724	$ 1,683,642	$ 12,463,366	$ 8,103,418	$ 4,359,948	$ -1,109,590
10,001-100,000	4	1,541,292	214,620	1,755,912	1,710,632	45,280	110,400
3,001-10,000	15	1,110,150	104,690	1,214,840	1,264,395	-49,555	139,890
1,001-3,000	47	1,663,142	85,500	1,748,642	1,950,745	-202,103	322,695
501-1,000	40	567,960	20,285	588,245	752,560	-164,315	168,035
<500	96	527,712	16,009	543,721	826,944	-283,223	241,655
Counties and Municipal Districts	5	35,735	85	35,820	51,820	-16,000	19,565
Waterworks Reporting	209	$ 16,225,715	$ 2,124,831	$ 18,350,546	$ 14,660,514	$ 3,690,032	$ -107,350

Source: Department of Municipal Affairs. Annual Report 1967. Edmonton: Queen's Printer, 1969.

Note: a, b, c, d, e, f, see Table 11.

TABLE 17

STRUCTURE OF FINANCIAL RETURNS OF WATERWORKS REPORTING, BY POPULATION SIZE, ALBERTA, 1966

(Expenditures = 100)

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)[a]
>100,000	2	118.90	19.91	138.81	38.81	-11.35	27.46
10,001-100,000	4	75.43	25.42	100.85	0.85	6.19	7.04
3,001-10,000	15	83.34	10.54	93.88	-6.12	12.82	6.70
1,001-3,000	47	83.86	4.88	88.74	-11.26	16.06	4.80
501-1,000	40	73.96	3.96	77.92	-22.08	24.53	2.45
<500	96	64.32	2.58	66.90	-33.10	32.13	-0.97
Counties and Municipal Districts	5	70.76	0.01	70.75	-29.25	23.87	-5.38
Waterworks Reporting	209	101.69	16.20	117.89	17.89	0.03	17.92

[a] Operating Surplus or Deficit plus Net Transfers from General Revenue Fund.

TABLE 18

STRUCTURE OF FINANCIAL RETURNS OF WATERWORKS REPORTING, BY POPULATION SIZE, ALBERTA, 1967

(Expenditures = 100)

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)[a]
>100,000	2	133.03	20.77	153.80	53.80	-13.69	40.11
10,001-100,000	4	90.10	12.55	102.65	2.65	6.45	9.10
3,001-10,000	15	87.80	8.28	96.08	-3.92	11.06	7.14
1,001-3,000	47	85.26	4.38	89.64	-10.36	16.54	6.18
501-1,000	40	75.47	2.70	78.17	-21.83	22.33	0.50
<500	96	63.81	1.94	65.75	-34.25	29.22	-5.03
Counties and Municipal Districts	5	68.96	0.16	69.12	-30.88	37.76	6.88
Waterworks Reporting	209	110.68	14.49	125.17	25.17	-0.73	24.44

[a] Operating Surplus or Deficit plus Net Transfers from General Revenue Fund.

Factors Influencing Financial Returns

Economies of scale is the term frequently used when describing the phenomenon of decreasing costs per unit of output as the plant size increases and consequently total output increases. This section of the study traces the individual revenue and expenditure items of Alberta waterworks as they alter with the scale of operation. In Tables 19 and 20 revenue and expenditure data per one hundred cubic meters of gross pumpage are presented. In these tables a comparison is made between waterworks of three different scales of operation, where the largest group averages 633 times more piped water than the smallest one (see Table 5). The unit expenditure of the 86 small waterworks is about 3.8 times the expenditure shown by the 8 large waterworks. Parallelling the cost is the increase of average operating revenues per unit of output as the scale of waterworks operation decreases. Water users served by the smallest waterworks group pay on the average three times more per unit of piped water than their counterparts served by waterworks of the biggest scale of operation. Yet sales revenues cover only 65 percent of total expenditures in the third group, compared to 75-85 percent in the first. Consequently, the contribution from general revenue (taxes) per unit of water in the third group is almost 15 times higher than in the first group.

To a large extent, the scale of the waterworks operation depends upon the population of the municipality served.[1] For this reason, a tabulation, where the breakdown of revenue and expenditure data is based on

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[1] There are exceptions to be found to this rule of thumb. For example, the town of Redwater, with less than 10,000 residents, is served by a waterworks which has a gross pumpage well over one million cubic meters per annum. This is because of a nearby industry which is very water intensive.

TABLE 19

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY SIZE OF WATERWORKS, ALBERTA, 1966

(Dollars per 100 Cubic Meters)

Size of Waterworks	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
Gross Pumpage >1 mil. m^3/yr.	8	$ 7.27	$ 3.23	$ 10.50	$ 9.99	$ 0.51	$ 0.86	$ 1.37
Gross Pumpage >100,000 m^3/yr.	57	14.80	1.38	16.18	18.40	-2.22	3.61	1.39
Gross Pumpage <100,000 m^3/yr.	86	24.19	1.60	25.79	37.17	-11.38	12.88	-1.50
Waterworks Reporting	151	$ 19.75	$ 1.60	$ 21.35	$ 28.64	$ -7.29	$ 8.65	$ -1.36

TABLE 20

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY SIZE OF WATERWORKS, ALBERTA, 1967

(Dollars per 100 Cubic Meters)

Size of Waterworks	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
Gross Pumpage >1 mil. m^3/yr.	8	$ 8.30	$ 2.01	$ 10.31	$ 9.92	$ 0.39	$ 0.74	$ 1.13
Gross Pumpage >100,000 m^3/yr.	57	15.34	1.15	16.49	18.25	-1.76	3.40	1.64
Gross Pumpage <100,000 m^3/yr.	86	24.99	0.71	25.70	38.25	-12.55	12.88	-0.33
Waterworks Reporting	151	$ 20.46	$ 0.95	$ 21.41	$ 29.19	$ -7.78	$ 8.59	$ -0.81

the population size of a municipality has been made (Tables 21 and 22). In these tables the impact of a waterworks scale of operation is even more clearly demonstrated than in the previous ones where the waterworks classes were rather broad. As population increases there is a decrease in the average expenditure and operating revenues per unit of water produced. The same is true with regard to the amounts of net tax transfers required. The financial statistics presented quite conclusively show that in a small municipality served by a small scale waterworks, water is more expensive to users and to municipal taxpayers.

In Tables 23 and 24 the impact of utilization of different sources of water upon the financial situation of a waterworks is evaluated. It is known that surface water needs more processing to make it suitable for human use. On the other hand, water from underground sources requires pumping and, in many cases, treatment by chemicals in order to decrease hardness of intake water. When the financial data from the waterworks utilizing different water sources are compared with the overall averages from all reporting Alberta waterworks, waterworks utilizing surface sources (except those drawing water from reservoirs) show better financial performance than those pumping water from wells.[1]

In the Appendix II the tabulation of financial returns in dollars per person served by size of waterworks, municipality size, and primary source of water is given (Tables 1 to 6). Similar conclusions can be drawn from these tables as were drawn from the tables of the unit costs and returns presented above.

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[1] The tabulations do not permit a separation of the "scale effect" and "source effect" on water production costs. In Chapter IV the effects are separated statistically.

TABLE 21

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY POPULATION SIZE, ALBERTA, 1966

(Dollars per 100 Cubic Meters)

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
>100,000	2	$ 7.55	$ 1.24	$ 8.79	$ 9.30	$ 2.49	$ -0.52	$ 1.97
10,001-100,000	4	9.24	5.78	15.02	15.09	-0.07	1.81	1.74
3,001-10,000	14	15.65	2.09	17.74	18.75	-1.01	2.78	1.77
1,001-3,000	36	15.76	1.13	16.89	19.72	-2.83	3.62	0.79
501-1,000	31	20.91	1.09	22.00	28.52	-6.52	8.38	1.86
<500	62	22.79	0.66	23.45	35.34	-11.89	14.18	-2.29
Counties and Municipal Districts	2	41.37	35.71	77.08	102.40	-25.32	5.08	-20.24
Waterworks Reporting	151	$ 19.75	$ 1.60	$ 21.35	$ 28.64	$ -7.29	$ 8.65	$ -1.36

TABLE 22

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY POPULATION SIZE, ALBERTA, 1967

(Dollars per 100 Cubic Meters)

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
>100,000	2	$ 8.30	$ 1.29	$ 9.59	$ 6.26	$ 3.33	$ -0.77	$ 2.56
10,001-100,000	4	10.76	3.25	14.01	14.53	-0.52	1.69	1.17
3,001-10,000	14	16.94	2.00	18.94	19.56	-0.62	2.57	1.95
1,001-3,000	36	16.33	0.96	17.29	19.13	-1.84	3.50	1.66
501-1,000	31	21.83	0.94	22.77	29.74	-6.97	8.08	1.11
<500	62	23.07	0.56	23.63	36.86	-13.23	13.18	-0.05
Counties and Municipal Districts	2	49.00	0.22	49.22	84.18	-34.96	39.38	4.42
Waterworks Reporting	151	$ 20.46	$ 0.95	$ 21.41	$ 29.19	$ -7.78	$ 8.59	$ -0.81

TABLE 23

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY PRIMARY SOURCE OF WATER, ALBERTA, 1966

(Dollars per 100 Cubic Meters)

Primary Source of Water	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
Wells	75	$ 21.85	$ 1.64	$ 23.49	$ 31.26	$ -7.77	$ 10.14	$ 2.37
Rivers	36	15.67	2.20	17.87	20.98	-3.11	4.60	1.49
Irrigation System	12	10.80	0.40	11.20	14.73	-3.53	6.27	2.74
Reservoirs	17	24.04	1.81	25.85	42.43	-16.58	14.56	-2.02
Lakes	6	17.97	0.26	18.23	22.36	-4.13	5.52	1.39
Other	5	26.76	0.40	27.16	38.73	-11.57	4.93	-6.64
Waterworks Reporting	151	$ 19.75	$ 1.60	$ 21.35	$ 28.64	$ -7.29	$ 8.65	$ -1.36

TABLE 24

REVENUE AND EXPENDITURE PER UNIT OF GROSS PUMPAGE, BY PRIMARY SOURCE OF WATER, ALBERTA, 1967

(Dollars per 100 Cubic Meters)

Primary Source of Water	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
Wells	75	$ 22.19	$ 0.70	$ 22.89	$ 32.11	$ -9.22	$ 10.66	$ 1.44
Rivers	36	16.40	1.43	17.83	21.39	-3.56	4.30	0.74
Irrigation System	12	11.03	0.14	11.17	16.48	-5.31	5.37	-0.06
Reservoirs	17	27.05	1.93	28.98	41.89	-12.91	13.10	-0.19
Lakes	6	17.24	0.23	17.47	22.44	-4.97	5.28	0.31
Other	5	27.86	0.56	28.42	37.08	-8.66	5.18	-3.48
Waterworks Reporting	151	$ 20.46	$ 0.95	$ 21.41	$ 29.19	$ -7.78	$ 8.59	$ 0.81

From all the tables presented in this section, three aspects of the financial situations are evident. First, there are significant economies of scale in water production. The average cost per unit of water produced declines as the output increases. Second, water users and municipal taxpayers do pay less in municipalities served by large waterworks. Third, the source and quality of the intake water has some impact on treatment costs and thus on the average cost.

CHAPTER III

STRUCTURAL RELATIONSHIP OF DEMANDS FOR WATER BY MUNICIPALITIES AND BY RESIDENTIAL WATER USERS, IN PARTICULAR: EMPIRICAL FINDINGS, THEORY AND ANALYSIS

Empirical Findings of Previous Studies

The demand for water by municipalities and by their residential customers, in particular, has been the topic of several research projects conducted in Canada and in the United States. These studies try to determine the main factors affecting levels of water use and to develop models which can be used to forecast future water demands. In the past, water supply managers have tended to assume that physical requirements per person govern water use, and that forecasting future water use consists merely of projecting the population growth and multiplying it by the per person "requirement".[1] Although it is true that population is the most significant determinant of water demand, the studies mentioned above have shown that there are also other factors which have a measurable effect on the per person consumption of water, and some of them are subject to management. In almost all water demand studies, some field data collection has been required, and this is to a large degree responsible for the variety of approaches and sometimes contradictory or inconclusive results; the demands for water are distributed unevenly over time and space. Furthermore, most water use studies differ in the choice of variables to be correlated with water use. If these components are aggregated the

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[1] P.W. Whitford, "Residential Water Demand Forecasting," Water Resources Research, Vol. 8, No. 4, (1972), p. 829.

correlation is weakened, writes Whitford[1] when referring to Saundreas' results from 93 metropolitan areas.

It is generally agreed that within the same cultural matrix, the level of community water use is a response to such factors as geographical location, climate, economic level, price, relative magnitudes of major classes of municipal water users, degree to which industrial water needs are met by municipal waterworks, and water system efficiency.

As used herein, the demand for water is defined in economic terms; that is, the amount of water for which individual customers would pay rather than go without. Consequently, the value of water may be considered as the maximum amount users will pay before reducing the amount of water used or entirely foregoing a specific use.

The following discussion will be focussed on the factors which have been found significant in explaining the level and fluctuation of residential, commercial and/or total municipal water use in previous studies. The industrial component of community water demand is affected by a different set of factors including a more extensive set of technological alternatives, and type of production. The quantity of water taken by commercial establishments is considered to be determined by: 1) per person income; and 2) the extent of commercial services; i.e., whether they are more or less purchased by the community's own population. Furthermore, for many commercial establishments such as stores, offices, and service depots, water use is incidental to the operation and is comparable to

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[1] Ibid., p. 829.

domestic uses (drinking, sanitary facilities, washing and cleaning).[1] The demand for water for public use by municipalities is not, in many cases, demand by a purchaser from a separate supplier,[2] and the principal determinant seems to be the municipal area devoted to public parks.

All the reviewed studies attempt to model water use in terms of explanatory variables and thus go beyond the widely used approach of estimating "requirements" on the basis of professional judgment and past experience.

Physical Conditions

Geographic and climatic conditions influence to a large degree the need for differing amounts of water, especially water used to irrigate residential lawns and municipal parks. Climatic factors, such as precipitation and evapotranspiration, directly affect the amount of water required to keep lawns green. "Evapotranspiration" is a term which describes the loss of water from the surface of the ground other than by surface water runoff. The potential evapotranspiration for an area has been shown by Thornthwaite to relate to the area mean temperature and incidence of sun as expressed by the latitude of the area and month of the year.[3] The amount of water available to plants is affected not only

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[1] Ideally, a breakdown of commercial establishments by type of service should be done so that water use can be assessed for each group of homogeneous establishments. This procedure has been followed in a study done by Hittman Associates, Main I: A System of Computerized Models for Calculating and Evaluating Municipal Water Requirements, (Springfield, Virginia: Clearinghouse, 1969).

[2] In many cases, water used to irrigate municipal parks is not metered.

[3] C.W. Thornthwaite, "An Approach Toward a Rational Classification of Climate," Geographic Review, Vol. 38, (1948), pp. 55-94.

by precipitation, which adds moisture to the ground, and evapotranspiration, which takes it away, but also by the physical characteristics of a soil which determine its water storing capacity. Total irrigation water needs are a function of the lawn area to be irrigated, the water deficit, and also the length of the growing season which depends upon the geographic location of the area.

In a study carried out by Linaweaver, Geyer, and Wolff[1] at the John Hopkins University an attempt has been made to evaluate the impact of "climatic" conditions, i.e., precipitation and evapotranspiration, on total water use during the sprinkling season. It has been found that the actual sprinkling amounts to about 60 percent of the estimated requirements in more humid eastern regions of the United States and in the arid western regions, sprinkling demands follow potential evapotranspiration quite closely.[2] The sprinkling "requirement" is calculated on the basis of water balance, which may be algebraically expressed as:

$$WB = P - E$$

where:

WB is the seasonal (monthly) water balance (in millimeters); i.e., water surplus or deficit depending upon the values of precipitation and evapotranspiration,

P is the seasonal (monthly) precipitation (in millimeters),

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[1] F.P. Linaweaver, <u>et al</u>, <u>A Study of Residential Water Use</u>. (Washington, DC: GPO, 1967).

[2] C.W. Howe and F.P. Linaweaver, "Summary Report on the Residential Water Use Research Project," <u>Journal of American Water Works Association</u>, Vol. 59, No. 3, (1967), pp. 267-282.

E is the seasonal (monthly) potential evapotranspiration (in millimeters).

Wong used least squares analysis to estimate municipal water use per person per year for the City of Chicago and its 59 suburbs.[1] One of the independent variables in the estimating equation was the average of June, July and August temperatures. He reports that the average summer temperature has a significant impact on Chicago's water demand.

Commenting on a regional study done by Haver and Winter to estimate municipal water use for 13 cities in Ontario, Grima[2] reports that the number of days in June, July and August with a rainfall of 0.25 millimeters (0.01 inches) or more has not improved the explanatory power of the estimating equation significantly.

The evidence in the above studies is not conclusive. When a studied region is small or fairly homogeneous with respect to climatic factors, the effect of climatic differences on water use may be considered negligible since there are likely to be other water determinants with more pronounced variation and this may result in inefficient estimates of the regression coefficient. Since the water storing capacity of soil is dependent not only upon the type of soil, but also plant cover, in this case, perennial grass, an elaborate survey of types of soil in municipalities may not be warranted.

Irrigable Area

Climatic conditions affect the levels of water use mainly during the

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[1] S.T. Wong, "A Model of Municipal Water Demand: A Case Study of Northeastern Illinois," Land Economics, Vol. 48, No. 1, (1972), pp. 34-44.

[2] A.P. Grima, Residential Water Demand: Alternative Choices for Management. (Toronto: University of Toronto Press, 1972), p. 41.

growing season when relatively large quantities of water are used to irrigate residential lawns and municipal parks. Several researchers have found that the lawn area is one of the main determinants of community water consumption and a prime contributor to summer water use peaks. Howe and Linaweaver's[1] study results have shown that the effect of the size of lawn is more pronounced in flat rate pricing areas. This would suggest that residential water users are more responsive to climatic conditions when the marginal price is zero than are their counterparts in metered areas where the marginal price is positive.

In order to meet the high seasonal demands, waterworks are required to build large system and plant capacities, with attendant fixed costs, that are not fully utilized most of the year. The ratio of the peak-hour rate to the average annual use may be as high as 8:1.[2] For this reason many municipalities' waterworks are directed to meeting maximum day demands rather than peak-hour demands.

There are other researchers who argue that frequency of lawn watering is directly influenced by the income level of the residential customer. Grima observes that, "generally speaking, lawns in higher income areas are greener."[3] Furthermore, the variation in the size of lawn or size of

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[1] C.W. Howe and F.P. Linaweaver, "The Impact of Price on Residential Water Demand," Water Resources Research, Vol. 3, No. 1, (1967), p. 26.

[2] F.P. Linaweaver, et al, "Use of Peak Demands in Determination of Residential Rates," Journal of American Water Works Association, Vol. 56, No. 4, (1964), p. 405.
In Edmonton, the ratio of the peak-hour rate to the average annual use is 3.5 : 1.

[3] A.P. Grima, Residential Water Demand, p. 44.

lot[1] are not likely to be great compared to differences in income.

Economic Level of Consumers

Wealth and/or income of residential consumers are the factors most frequently accepted as determinants of residential water use. This is because income is closely associated with the ability to pay for goods in general. Also, as affluence increases, the ability to use more water increases, i.e., people are able to afford such water-using appliances as washing machines, dish washers, and air conditioners or humifiers, and have more spacious homes with larger lawns.

In research done by Headley[2] in the San Francisco-Oakland metropolitan area, the relationship between water demand and income is studied. Headley reports that the income elasticity[3] of demand for residential water use is about 1.5 when estimated from cross-sectional data. However, when time-series data have been used, the average income elasticity is only about 0.2. This low elasticity suggests that the rise in income is not promptly followed by increased water use, because many water-using appliances are durable in nature (baths, washers, etc.). The difference between low

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[1] Since it is difficult to obtain data on size of lawn, Kellow suggests using size of lot instead. In his study on residential water demand in Calgary, he found that lot size is a good substitute for lawn size. R.L. Kellow, "A Study of Water Use in Single-Dwelling Residences in the City of Calgary, Alberta." (Unpublished M.Sc. thesis, University of Alberta, 1970), p. 131.

[2] J.C. Headley, "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area," Land Economics, Vol. 39, No. 4, (1963), pp. 441-449.

[3] The term "income elasticity" expresses the relationship between the percentage change in the quantity of a commodity bought and the percentage change in the income.

income elasticity derived from the time-series data and high elasticity estimated from the cross-sectional data can be explained as follows: a high income residential district may be expected to include a large percentage of customers who possess water-using appliances and large lawns; with the rise in income over time, the increase in water use is much slower since many of the durable water-using goods have been already acquired by affluent customers.

It is, however, difficult to obtain income flow data from individuals and for this reason attention has been given to the possession of water-using durables or other measures of real estate. Based on the assumption that people tend to live in homes whose value bears some relation to their income, North,[1] in his study, found that the market value of the home is more closely associated with water use levels than income. Kellow,[2] using the assessed value of the home as a surrogate for the market value obtained from public records, demonstrates that the explanatory power of the estimating equation is not decreased by this substitution.

Household Size

Given the climatic conditions and the income (wealth) level, the amount of water used in a household is strongly influenced by the number of people residing in the household. The results from several studies suggest that even though there are some minimum quantities of water required

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[1] R.M. North, "Consumer Responses to Prices of Residential Water." (Paper presented at the American Water Resource Conference, San Francisco, California, 1967), p. 8.

[2] R.L. Kellow, "A Study of Water Use in Single-Dwelling Residences," p. 131.

to meet the basic sanitation needs of each household member, the overall average of water use per person tends to decrease as household size increases regardless of the income level.[1] Water consumption per household can be expected to increase as household size increases, but at a decreasing rate. The elasticity coefficient calculated by Grima[2] is about 0.6.

Mode of Pricing

In the previous chapter, water consumption data were compared for municipalities which meter water use and those which do not. The average annual gross pumpage in metered Alberta municipalities was 133 cubic meters per person as compared to 221 cubic meters per person per year in municipalities which do not meter water use to their customers.[3] Similar evidence with respect to higher per person water consumption in flat rate pricing municipalities is also presented in several studies done in this field.[4] One of the main reasons why the levels of water use are generally lower in metered municipalities is that metered rates do impose

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[1] See, for example: Hittman Ass., Main I, pp. 20-22; and D.F. Dunn and T.E. Larson, "Relationship of Domestic Water Use to Assessed Valuation with Selected Demographic and Socio-Economic Variables." Journal of American Water Works Association, Vol. 55, No. 4, (1963), pp. 441-450.

[2] A.P. Grima, Residential Water Demand, p. 111.

[3] For more details, see Tables 6 and 7, pp. 19-20.

[4] For example, the 1962 edition of Canadian Municipal Utilities claims that 100 percent metering reduces water consumption by 40 to 60 percent.
Canadian Municipal Utilities, Waterworks Manual and Directory. (Toronto: Monetary Times Publications Ltd., 1962), p. 57.
Hanke and Flack give evidence from Colorado that the introduction of metering reduced the annual and summer water use by 34 and 37 percent, respectively.
S.T. Hanke and J.E. Flack, "Effects of Metering on Urban Water," Journal of American Water Works Association, Vol. 60, No. 12, (1968), p. 1364.

marginal monetary costs on the consumer and thus provide an incentive to curtail the less essential water uses. When flat rates are levied the only significant incentive to halt the use of more water will be from negative effects due to excessive water use, such as seepage into basements caused by excessive lawn irrigation. The results from the Hopkins' study demonstrate the phenomenon as follows: average household uses differ little between metered and unmetered areas, but sprinkling uses and summer peak demands are more than double in flat rate areas.[1] This indicates that sprinkling uses are more price elastic due to the greater degree of substitution that can occur in sprinkling uses, most notably, in the greater efficiency of sprinkling.

Price of Water

The general law of demand states that the amount demanded increases with a fall in price, and diminishes with a rise in price. One of the reasons is that the customer has a limited income and limited assets. To buy more of one commodity, the expenditure on some other commodity has to be curtailed, and this trade-off will be greater, the higher the price of the commodity and will be of greater importance to his welfare, the lower his income. However, this argument is not widely accepted by waterworks managers. It is argued that water demand is insensitive to price because it is a small item in the family budget and there are hardly any

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[1] F.P. Linaweaver, A Study of Residential Water Use, pp. 269-271.

substitutes for water.[1] Under present pricing systems a large proportion of the water bill is fixed, irrespective of the amount of water used (see Table 10, p. 28) and even where water is metered; thus, the effect of price upon water use is diminished.

Contrary to the deductive argument, several researchers have provided empirical evidence of what appears to be a significant price effect. Howe and Linaweaver[2] found that price elasticity of water is smallest for indoor use (-0.23) and it is about -0.7 for sprinkling use in the western regions of the United States. In humid eastern areas of the United States, sprinkling demands do respond substantially to price charge (price elasticity is -1.25).

Grima[3] reports that when prices are low, water uses are more responsive to price increases since "at a high price less desirable water uses have already been discarded." The price elasticities of residential water, determined by household cross-sectional study, are reported to be -0.75 and -1.07 for the winter and summer period, respectively.

When average prices and consumption for municipalities are compared, the estimated elasticities are lower and range from -0.25 to -0.4 at the means (e.g., Fourt, Haver and Winter, Turnovsky).[4] Wong,[5] on the other hand, found no significant impact of price on water use in Chicago.

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[1] The average total expenditure per dwelling unit in the sample analyzed by Howe and Linaweaver was one percent per year which included water and sewer charges.
C.H. Howe and F.P. Linaweaver, "The Impact of Price on Residential Water Demand and its Relation to System Design and Price Structure," p. 19.

[2] Ibid, p. 29.

[3] A.P. Grima, Residential Water Demand, p. 113-114.

[4] Ibid, p. 57.

[5] S.T. Wong, "A Model of Municipal Water Demand," p. 43.

The results discussed above are not fully comparable because there is no uniform pricing policy among municipalities and regions. For example, the predominance of several declining block rates in metered municipalities means that not all residential users are facing the same price. Smaller users are paying higher marginal price and thus an estimated demand curve for individual households from municipalities merely reflects the fact that the lower price is charged when the quantity demand is high and vice versa.

Theory and Analysis

The theoretical and empirical work described in the following sections is designed to evaluate the hypothesis that community and residential water uses vary with a number of factors such as the economic level of the consumer, climate, and whether consumers have metered or flat rate service. The theoretical equation is fitted to sample data obtained from a survey in the Province of Alberta and is tested statistically.

Two variations of the model are formulated. Total community water use in cubic meters per person averaged over the two year period is the variable to be estimated in the first, and residential use per resident averaged over two years in the second. Municipalities having metered or flat residential rates are treated separately since it is expected that the mode of pricing has some impact upon the demand behaviour of the customer.

Structure of the Demand Models

Factors Affecting Levels of Residential Water Use

The daily quantities of water used by residential customers in Alberta by far exceed the physiological requirements (about 1 litre per person).[1] Thus, the major determinants of the quantity of water used are the water-using appliances and the irrigable area. Essentially, residential water use is complementary to other household activities and is dependent upon the consumer's ability and willingness to purchase water-using durables.

Total residential water demand is a composite demand, i.e., the sum of water used to complement activities indoors (e.g., washing) and outdoors, especially for sprinkling purposes. Based on findings from the previous studies discussed earlier, there is a hierarchy of water-complementary activities as reflected in the price elasticity of the associated water demand. This would suggest that an appropriate pricing policy is more suitable to residential water use management than any form of regulation or physical restriction because it respects the consumer's right to choose to use water for some purposes rather than for others.

The composite nature of residential water demand is the main reason for its high seasonal variation. During periods of hot dry weather more water is used for lawn sprinkling, showers and direct ingestion.[2] The

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[1] B.H. Dietrich and J.M. Henderson, Urban Water Supply Conditions and Needs in Seventy-Five Developing Countries, World Health Organization Public Health Papers No. 23. (Geneva: WHO, 1963), p. 27.

[2] Evaporative coolers are not used in single detached dwellings in Alberta.

seasonal fluctuation in demand is considered critical in the design of water supply systems.

Even though there are likely to be numerous factors that may affect the magnitude of residential water use (e.g., habits, availability of leisure time, housing pattern, etc.) their relative importance varies among customers. For this reason, main emphasis will be given to those variables that are relevant to most residential users and are, to a certain degree, controllable by waterworks' management.

The causality of residential water use can be presented as follows: family income determines the level of water-complementary activities; family size influences the frequency of the equipment use; climatic conditions affect the duration of the use; technology sets up limits of technical efficiency; and mode of pricing and price itself induce the consumer to use water more efficiently.

Factors Affecting Levels of Community Water Use

Community water demand is a composite demand and is the sum of water quantities used for residential, commercial, industrial, and public purposes. It is realized that not all the factors which have been demonstrated to have an influence upon the residential water use in the previous studies are to the same degree relevant in explaining the variations in the remaining three major uses. This is especially true in the case of industrial water demand which is affected primarily by the nature of the product being produced and the technology used. It is a common practice for an industry using large quantities of water to have its own water supplies and thus it is only to a limited degree dependent upon the municipal waterworks.

There are two main uses of water by commercial establishments: water used for sanitation purposes, and water which is used as an input to produce such saleable services as car washing, cloth cleaning, and catering services. The relative importance of those basic water uses varies with the type of business the individual establishment is engaged in. Other factors which may have some effect on the scale of commercial activities are the wealth of the community residents and the degree to which the services are utilized by the local people.

The irrigable area of municipal parks is the prime determinant of public water use. The intensity and duration of the irrigation is influenced by climatic factors and also by the local preference for green lawns. Since most of Alberta municipalities have paved roads, dust cropping, once a very important segment of public water use, now accounts for an insignificant portion of the municipality's public water use. As the affluence and availability of leisure time increases the residents demand greater areas devoted to parks and also utilization of the existing parks is increased which necessitates greater care in the form of fertilizing and watering by the local parks department.

In summary, there are some factors which affect all four main components of a community's water use; most notably, the price of water, mode of pricing, personal income and/or wealth, and climatic characteristics of the locality. However, there are other determinants, such as type of industrial and/or commercial activities, and degree of dependability of the large industrial users on municipal waterworks, which are significant enough to warrant treatment of each of the uses separately.

The Hypothesized Functional Relationship

The functional relationships describing water use for the entire community and its residential components in terms of the parameters in the models could be expressed as:

$$TP_p = f(A_p, E_u, BQ, HS, PD, MP) \quad (1)$$

and

$$RU_r = f(A_p, BR, BQ, MR, HS, PD, MP) \quad (2)$$

The linear regression relationship may be written:

$$D = \frac{TP_p}{RU_r} = a_0 + a_1A_p + a_2E_u + a_3BR + a_4BQ + a_5HS + a_6MR +$$

$$a_7PD + a_8MP + U \quad (3)$$

where:

$a_{0,1\ldots8}$ are the regression coefficients (although a_0 is usually termed the intercept or constant term);

TP_p is the total pumpage of municipality i in cubic meters per person per year (2 year average);

RU_r is the residential water use in municipality i in cubic meters per resident per year (2 year average);

A_p is the assessed value of land and buildings in municipality i per person (2 year average);

E_u is the expenditure of municipality i per cubic meter of tap water (2 year average);

BR is the base rate (the fixed bill) for one year per residential account;

BQ is the base quantity in cubic meters per residential account per year that is allowed with the base rate;

HS is the number of persons in the dwelling unit;

MR is the marginal rate (variable price) of residential water in the first block;

PD is the precipitation deficit in millimeters in municipality i for May-September period (2 year average);

MP is the mode of pricing of residential water (metered, flat or assessed flat rate);

U is the error of the equation having the usual stochastic characteristics.

Since there are no *a priori* reasons indicating whether the functional form of the relationship will be linear or multiplicative, both forms will be examined and the equations of "best fit" will be selected. The magnitude of the regression coefficients cannot be specified *ex ante*; however, the sign of the coefficients of A_p, BQ, PD is expected to be positive while the coefficients of E_u, BR, MR, HS should be negative.

Description of Independent Variables

Assessed Value of Land and Buildings

The conventional economic theory assumes that the demand for a particular good is influenced by the price of the good, the income and/or wealth of the buyers, and prices of substitutes. Since other income or wealth data were not available and one of the objectives of this study was to examine the possibility of using readily available data in the model, average assessed value of land and buildings per person has been

chosen as the surrogate indication of the wealth of customers in Alberta municipalities.[1] The inclusion of land value gives some indication of the size of the potential irrigable area in the municipality.

The relevance of this surrogate in explaining the variation in residential water use may be diminished by the nature of this variable, an aggregate estimate of the values of residential, commercial, industrial and municipal properties.

Price

As has been shown in the previous chapter, there are basically two widely used pricing schemes under which the customers pay for the services provided by waterworks in Alberta. These are metered block rates and flat rates.[2]

It is not uncommon to find both pricing schemes in one municipality where the residential customers may be charged flat rates, while the commercial and industrial customers pay on the basis of water actually used. The situation is complicated even when all customers are metered. The rate is composed of the "base rate" which usually includes a "free" quantity of water, and the "unit rate" which often decreases as the quantity used by a customer increases (in which case it is called a "block rate").

Based on this reasoning, the average annual waterworks expenditure per cubic meter of water supplied (E_u) has been employed as an alternate

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[1] Assessed land and buildings value are abstracted from 1966, 1967 Annual Reports, published by the Alberta Department of Municipal Affairs.

[2] When the flat rate is based on some predetermined criteria such as the number of water-using appliances, lawns areas, family size, etc., this rate is often termed the assessed flat rate. For example, the majority of residential users in Calgary are subject to this pricing scheme.

estimate of the water price which has to be borne by all users in the municipality. This variable will be examined in the equation estimating total community pumpage.

The base rate is a relevant variable in all Alberta municipalities regardless of the pricing scheme employed even though the rationale behind is dependent upon the particular pricing policy. In flat rate pricing municipalities, the residential customer is paying some predetermined base rate which is not directly influenced by the amount of water actually taken. It is the only direct payment under the flat rate pricing scheme.

The base rate to a residential customer in metered municipalities represents the minimum price he has to pay for the privilege of being served by the waterworks.

Water consumption in excess of minimum allowance is charged at the "commodity" price which will be referred to as the variable or marginal rate. Frequently, the marginal rate declines as the quantities of water drawn by the customer exceed the specified "block" amount. In most municipalities, average residential water use does not exceed the quantity subject to the first block rate. For this reason the marginal rate applicable in the first block will be tested in the equation estimating residential water use.

It is hypothesized that the coefficients of expenditure per unit of water and marginal rates should have negative signs. In the case of flat rate pricing, the base rate may induce customers to "maximize returns" of their water payments by increasing water use; hence the coefficient is expected to be positive. Customers in metered municipalities are expected to be more influenced by the amount of the water bill than by marginal price because in most instances, only a single amount is shown on the bill they receive, and rates are not readily known. Thus, the coefficient of base

rate is expected to be negative.

Base Quantity of Water Allowed with the Base Rate

It is hypothesized that when the allowance is greater than the inelastic needs, customers will expand water use "to get full value" for their outlay. The rationale is similar to that of the base rate in flat rate pricing municipalities. A small but positive coefficient is expected.

Household Size

Water use per household should increase with the number of persons per household. Because there are some basic sanitation needs of each household member, this particular use of water may be expected to be a linear function of the number of persons in the residence. Other uses should be independent of household size. Hence, the average (per person) use should decline with household size.

Precipitation Deficit

This variable is the non-negative difference of the precipitation and potential evapotranspiration.[1] It is mainly sprinkling demand that is strongly influenced by the magnitude of this variable. Data regarding other physical factors also known to affect the amount of water required to keep the lawn green, such as the water storing capacity of soil, are not available. The regression coefficient is expected to be positive.

In this cross-sectional study the impact of the precipitation deficit

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1 An excess of former over the latter represents a surplus which is ignored.

may not be fully revealed since the variance with respect to the growing season's precipitation and temperature is not large among the municipalities in the province.

Mode of Pricing

It is assumed that metering of actual consumption provides an incentive to customers to use water more efficiently. It is expected that the impact of metering will be more pronounced in municipalities in which base water allowance is relatively small and the marginal rate higher.

Even though the assessed flat rates are more equitable than flat rates (because the former scheme is somewhat related to the actual water use level), they too should influence water demand as any other flat rate.

Description of Dependent Variables

As has been pointed out in the previous chapter, the accuracy of total pumpage and water use by class of customer data are subject to errors of measurement. Not all Alberta waterworks have the facilities to accurately measure the amount of water withdrawn and/or may keep the records of water quantities lumped together as an aggregate for residential, commercial, industrial and public uses.

Since multiple-dwelling units (apartment buildings) are often registered as commercial entities in municipal records, including those kept by the waterworks, "residential water use" as used in this study refers only to water supplied to single-dwelling units. For this reason the following formula has been used to estimate the residential water use per resident:

$$RU_r = (RU/RA) \; / \; HS$$

where:

- RU_r is the residential water use per resident;
- RU is amount of water supplied to single-dwelling units;
- RA is the number of residential accounts (which has been found to be almost identical to the number of single-dwelling units);
- HS is the average household size (calculated as: total population/number of all dwelling units).

In any Alberta municipality, there are some households not being served by the waterworks (see Table 1, p. 9) and also a number of waterworks provide services beyond the corporate limits of a particular municipality. In this study, the variable expressing total pumpage per person has been adjusted for the above considerations.

It should be noted that both of the dependent variables represent the averages of 1966 and 1967 pumpage and consumption data.

Estimating the Parameters

In this study two alternate methods of determining the effect of pricing mode will be used. Parallel estimates equation (5) *versus* equation (7) will be done separately for each pricing mode class. The dummy variable estimates will be done by combining all mode pricing classes and specifying a variable which takes the value one in case of one pricing mode, and zero for all other pricing mode classes. If there are (n) pricing modes, (n-1) dummy variables are necessary and sufficient to uniquely identify each class. The dummy variable method gives more reliable estimates provided that the response pattern of demand, i.e.,

the relation to other than the dummy variables, is similar regardless of pricing mode.

The regression coefficient associated with a pricing mode variable estimates the difference in the average water use or pumpage over the pricing mode with value zero; it is considered a "demand shifter".

The technique of least squares will be used in the derivation of coefficients of the postulated explanatory variables. In order to ensure the "best" and "unbiased" regression coefficients, the following assumptions of least squares analysis should be met:

1) The explanatory variables are linearly independent of one another.
2) The explanatory variables are independent of the residuals from regression.
3) The expected value of the residuals is zero; and the variance of the residuals is constant over the range of data considered.
4) There is a linear relationship between the dependent variable and the explanatory variables and a disturbance term.
5) The explanatory variables are random variables and contain no random errors (i.e., represent the population).
6) The number of observations is greater than the number of parameters to be estimated.

The partial regression coefficient (b_i) indicates how much the dependent variable will change, per unit change in the independent (or explanatory) variable, provided the other independent variables do not change, i.e., ceteris paribus.

Essentially, there are four statistics on the basis of which the equation of "best fit" may be chosen. These are:

1) The coefficient of determination (R^2) indicating the fraction of the total variation in the dependent variable associated with the

variation in explanatory variables.

2) The F-value showing the ratio of the explained variance to the unexplained (residual) variance.

3) The multiple standard error of the estimate ($S_{\bar{Y}}$) measuring the preciseness of prediction of the dependent variable on the basis of the explanatory variables.

4) The standard errors of the regression coefficients indicating the degree of significance of the individual regression coefficients in the equation.

In regression analysis the error from the equation may be attributed to: 1) measurement errors; 2) imperfect or incorrect specification of the form of the equation; and 3) the inherent irreproductibility of biological and social phenomena.[1]

Empirical Results

Residential Water Use in Metered Municipalities

Even though the number of Alberta municipalities metering their residential customers is at least 87,[2] only for 27 communities could all data required by the estimating equation be secured. The means, standard deviations and coefficients of variation for all variables in this sample are given in Table 25. The relatively low values of the coefficient of

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[1] R.J. Wonnacott and T.H. Wonnacott, Econometrics. (New York: John Wiley & Sons, Inc., 1970), p. 17.

[2] This datum indicates the minimum number of metered municipalities, since there are some municipalities which did not answer the survey question regarding the mode of pricing.

TABLE 25

MUNICIPALITIES METERING RESIDENTIAL WATER

(N = 27)

Variable	Mean Value	Standard Deviation	Coefficient of Variation
A_p	1.542	0.476	30.87
BQ	153.602	88.053	57.32
BR	38.610	15.710	40.69
MR	24.200	11.600	48.33
HS	3.700	0.400	10.81
PD	330.000	119.000	36.06
RU_r	76.451	21.599	28.25

Notes: A_p is the assessed value of land and buildings in thousands of dollars per person (2 year average);

BQ is the base quantity of water in cubic meters per residential account per year that is allowed with the base rate;

BR is the base rate in dollars per residential account per year;

MR is the marginal rate in cents applicable in the first block;

HS is the household size;

PD is the precipitation deficit in millimeters for May - September period (2 year average);

RU_r is the residential water use in cubic meters per person per year (2 year average).

variation for some variables, notably household size, assessed value and precipitation deficit, indicate close clustering around the means. This lack of variation increases the standard errors of the regression coefficients for the above variables. In Table 26 the matrix of correlation coefficients of variables tested by the estimating equation is presented.

The following theoretical equation has been assumed to "explain the variation in residential water use per resident per year:

$$RU_r = f(A_p, BQ, BR, MR, HS, PD) \tag{4}$$

TABLE 26

MUNICIPALITIES METERING RESIDENTIAL WATER (CORRELATION COEFFICIENTS)

(N = 27)

Variable	RU_r	BR	HS	BQ	A_p	PD
BR	-0.338					
HS	-0.332	0.420				
BQ	0.317	0.367	0.303			
AP	0.259	0.343	0.082	0.284		
PD	0.275	-0.800	-0.194	-0.287	0.323	
MR	0.376	0.133	-0.183	0.315	-0.098	0.158

For explanation of symbols see note to Table 25, p. 74.

The linear equation[1] which best fits to the sample data is:

$$RU_r = 146.358^{**} - 0.559BR^{*} + 0.139BQ^{**} - 18.622HS^{*}\quad[2] \qquad (5)$$

standard errors:	20.729	0.249	0.042	9.880
elasticity estimates:[3]		-0.282	0.279	-0.901

$R^2 = 0.43$ F-value $= 5.73^{**}$ N = 27

The above equation indicates that an increase of 10 cubic meters in the base quantity would lead to an increase of 1.4 cubic meters in the residential water use per resident per annum, ceteris paribus. When the annual base rate is increased by 10 percent, a decline of about 2.8 percent in the residential water use may be expected. The existence of economies of scale in residential water use is evident from the size of the coefficient of household size which indicates a decrease of over 18 cubic meters in the annual consumption per person when a household is enlarged by one person.

The regression coefficients of the variables in the above equation

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[1] The multiplicative form of the theoretical equation has also been tried; however, the equation of "best fit" which includes the same variables as equation (5) has only R^2 of 0.32. For more details see Appendix III where some alternate formulations are presented.

[2]
o significant at 90 - 95 percent level
* significant at 95 - 99 percent level
** significant at > 99 percent level

[3] Elasticity estimates at the average of the sample values calculated as follows:

$$E_{\bar{X}_i} = b_i \frac{\bar{X}_i}{\bar{Y}}$$

are statistically significant at high probability levels and have the expected algebraic signs. However, the equation's coefficient of determination of 0.43 indicates that there are additional general or local factors which affect residential water use.

The correlation between the residential water use and assessed value is low (Table 26). The latter variable, while indicating the expected direction of influence may not be suitable to predict residential water use in a cross-community context.[1] The insignificant regression coefficient of marginal rate and the positive relationship between the residential water use and this variable (see Table 26) may imply that the residential customer is more responsive to the actual size of a water bill, as given by the base rate, than to the marginal rate. As reflected in Table 26, the communities located in more arid areas tend to allow less water with the minimum bill which is for that reason lower (negative coefficient of correlation between BQ and PD).

Residential Water Use in Flat Rate Pricing Municipalities

There are not too many flat rate pricing municipalities in Alberta that can estimate the amount of water consumed by residents or for that matter by any other group of customers. In order to estimate the amount for a particular use, the gross pumpage and consumption data of the remaining users would have to be known. Complete data were available for

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[1] This finding is in contrast to Kellow's observation that assessed value is a good predictor of water use in a cross-sectional analysis of households within the same municipality (Kellow, "A Study of Water Use in Single-Dwelling Residences," p. 131.).

only eight Alberta communities.[1] In Table 27 the means, standard deviations, and coefficients of variations of the sample data are presented. The average residential water use in flat rate pricing municipalities is over 46 percent higher and the fluctuation around the mean is greater when the water use data in Tables 25 and 27 are compared, even though the average household size is somewhat greater in the flat rate pricing sample. However, this difference is not statistically significant.

The residential water use in flat rate pricing municipalities has been assumed to be the function of the following independent variables:

TABLE 27

MUNICIPALITIES WITH FLAT RATE RESIDENTIAL TARIFFS

(N = 8)

Variable	Mean Value	Deviation	Coefficient of Variation
A_p	1.519	0.590	38.84
BR	37.710	17.070	45.27
HS	3.800	0.340	8.94
PD	299.000	131.000	43.81
RU_r	111.842	45.354	40.55

For explanation of symbols see note to Table 25, p. 74.

[1] Calgary is included in this group, even though about 20 percent of residential customers are charged according to quantity of water taken.

$$RU_r = f(A_p, BR, HS, PD) \tag{6}$$

The linear equation which best fits the sample data is:

$$RU_r = 115.061^* + 1.884BR^o + 52.609A_p{}^o - 40.157HS \;^1 \tag{7}$$

standard errors:	43.275	1.105	33.512	54.257
elasticity estimates:		+0.635	+0.714	-1.364

$R^2 = 0.48$ F-value = 1.23 N = 8

The above equation indicates a relationship between water rate (BR) and residential water use (RU_r) that runs counter to the expectations of some because it shows a positive price elasticity of demand. This finding however, supports the argument stated earlier that water users maximize their satisfaction by increasing water withdrawal since rates are set independently of water use.[2] The increase in affluence, as represented by variable A_p, by 10 percent would be followed by 7.14 percent greater water use. The regression coefficient of household size points in the expected direction but is not statistically significant; it is a result of very small variation of this variable in the sample data (coefficient of variation is 8.94 percent).

In Table 28, which gives the correlation coefficients, an interesting

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[1] For explanation of symbols, see footnote 2, p. 76.

[2] This finding may yet be a statistical fluke, even though the coefficient of BR is significantly different from zero at 90 - 95 percent probability level, because there are very few observations in the sample.

TABLE 28

MUNICIPALITIES WITH FLAT RATE RESIDENTIAL TARIFFS

(CORRELATION COEFFICIENTS), (N = 8)

Variable	RU_r	HS	BR	A_p
HS	0.060			
BR	0.399	0.179		
A_p	0.314	0.347	-0.373	
PD	0.536	0.372	0.779	-0.002

For explanation of symbols see note to Table 25, p. 74.

relationship between the precipitation deficit base rate and residential water use can be observed. The positive sign and relatively high correlation coefficients suggest that waterworks located in more arid parts of the province tend to charge higher rates because the average residential water use is also greater.

Residential Water Use in a Combined Sample of Metered and Flat Rate Pricing Municipalities Related to Waterworks Expenditure

In order to find the impact of mode of pricing on average residential water use, a sample of 29 municipalities, all having the data required by the theoretical equation, was drawn. The theoretical equation has been expanded to include the average waterworks annual expenditure (cost) per 100 cubic meters of water produced. In Table 29 the characteristics of the sample data are presented. There are 22 municipalities metering their residential customers selected in the sample. Of the remaining seven mu-

TABLE 29

JOINT SAMPLE OF MUNICIPALITIES

(N = 29)

Variable	Mean Value	Standard Deviation	Coefficient of Variation
A_p	1.537	0.532	34.61
BR	42.460	11.210	26.40
HS	3.800	0.400	10.52
PD	259.000	48.300	18.65
E_u	19.700	10.790	54.77
RU_r	86.504	33.011	38.16

Notes: E_u is the average waterworks expenditure (cost) per 100 cubic meters in dollars (2 year average).

For explanation of the remaining symbols see note to Table 25, p. 74.

nicipalities, four communities use flat rate pricing and three communities charge their residential customers assessed flat rates. As in the previous two samples, the close clustering of household size values around the mean is evident also in Table 29.

The following theoretical equation is tested against the sample data:

$$RU_r = f(A_p, \text{BR or } E_u, \text{HS, PD, MP, AP, FP}) \qquad (8)$$

where:

A_p, BR, E_u, HS, and PD are the symbols of variables already defined above;

AP and FP are zero-one dummy variables of pricing mode;

AP is equal to one only for municipalities which have assessed pricing; in all other cases this dummy variable is equal to zero;

FP is equal to one only for municipalities which have flat rate pricing; in all other cases this dummy variable is equal to zero.

Municipalities with metered pricing are distinguished by a value of zero for both of the above variables.

The linear equation which best fits the sample data is:

$$RU_r = 121.876^* - 0.194E_u - 17.576HS + 16.209A_p^{\circ} + 39.902FP^* + 47.936AP^{*1} \quad (9)$$

standard errors: 54.692	0.697	14.681	12.263	17.393	20.053
elasticity coefficients:	-0.044	-0.772	+0.288	N.A.	N.A.

$R^2 = 0.45$ F-value $= 3.71^*$ $N = 29$

In the above equation the coefficients of average expenditure (E_u) and household size (HS) are not significantly different from zero but they have the expected negative sign. The magnitude of the coefficient of assessed value (A_p) indicates that a 10 percent difference in affluence is associated with a 2.9 percent increase in residential water use. However, the degree of responsivness, as measured by the coefficient of elasticity has declined in comparison to equation (7) based on observations

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[1] For explanation of symbols, see footnote 2, p. 76.

from flat rate pricing municipalities only. The main features of the above equation are the coefficients of mode of pricing. Both coefficients are significantly different from zero and have the expected sign. The magnitude of these coefficients implies that in flat rate pricing municipalities, the average annual residential use may be expected to surpass the consumption in metered areas by almost 40 cubic meters (50.3 percent) and in communities with assessed flat rate pricing by 48 cubic meters (60.3 percent).

The above results are also supported by the pattern of the correlation coefficients shown in Table 30. The correlation between the average residential water use in flat rate pricing municipalities is positive and significantly different from zero. In metered municipalities the opposite is true. The negative sign and significant coefficient of correlation between the average expenditure (E_u) and residential consumption demonstrate the effect of economies of scale in water production. And the magnitude of positive correlation between the base rate and average expenditure further amplifies the impact of size on the average expenditure and base rate. The negative correlation between the water use and precipitation deficit, which is contrary to expectation, is most likely caused by the nature of this combined sample.

Total Pumpage in a Combined Sample of Metered and Flat Rate Pricing Municipalities

The characteristics of the combined sample of 53 municipalities are given in Table 31. Comparison of the data statistics in Table 29 shows that the means and the standard deviations of all identical variables are very similar, since the two samples drawn from the same population universe

TABLE 30

JOINT SAMPLE OF MUNICIPALITIES (CORRELATION COEFFICIENTS)

(N = 29)

Variable	RU_r	PD	E_u	HS	A_p	BR	FP	MP
PD	-0.275							
E_u	-0.483	-0.007						
HS	-0.136	0.014	0.113					
A_p	0.248	-0.040	-0.469	0.136				
BR	-0.211	0.079	0.505	0.319	-0.584			
FP	0.296	-0.348	-0.209	0.268	-0.068	0.042		
MP	-0.563	0.348	0.476	-0.010	0.024	-0.032	-0.709	
AP	0.456	-0.095	-0.432	-0.163	0.044	-0.020	-0.136	-0.602

Notes: FP is the flat rate pricing;

AP is the assessed flat rate pricing;

MP is the metered pricing.

For explanation of the remaining symbols see note to Table 25, p. 74.

are known to overlap. The average total pumpage is greater than the average residential water use and this is to be expected.

The sample data were fitted to the following theoretical equation which includes dummy variables representing the mode of pricing:

$$TP_p = f(A_p, E_u \text{ or } BR, HS, PD, AP, FP) \qquad (10)$$

TABLE 31

JOINT SAMPLE OF MUNICIPALITIES -- TOTAL PUMPAGE

(N = 53)

Variable	Mean Value	Standard Deviation	Coefficient of Variation
A_p	1.460	0.449	30.75
BR	43.790	11.090	25.32
E_u	18.040	10.430	57.81
HS	3.770	0.420	11.14
PD	259.230	58.090	22.41
TP_p	148.550	106.771	71.87

Notes: TP_p is the total pumpage in cubic meters per person per year; excluding the sales of water to customers outside the corporate limits of a municipality (2 year average).

For explanation of the remaining symbols see note to Table 25, p. 74.

where:

TP_p is the total pumpage per person.

The other symbols have been described in the note to equation (8).

The linear equation which best fits the sample data is:

$$TP_p = 187.068 + 0.272PD^{o} - 3.782E_u^{**} - 17.759HS +$$

standard errors:	105.871	0.166	1.083	22.690
elasticity coefficients:		0.475	-0.460	-0.451

$$+ 24.579FP^{**} + 182.439AP^{**}\ [1] \qquad (11)$$

standard errors:	34.873	34.624
elasticity coefficients:	N.A.	N.A.

$R^2 = 0.65$ F-value $= 17.46^{**}$ $N = 53$

The above equation has an explained variation of 0.65 and all the variables have the expected signs. With the exception of the coefficient of household size, all remaining variables are significant at high probability levels. The "price" elasticity of -0.46, as indicated by the regression coefficient of average expenditure, shows a moderate degree of responsivness of all water users as a group to charges in water rates. Relatively small impact on the total pumpage may be expected as the result of fluctuation in precipitation deficit (an increase of 4.75 percent in the total pumpage is associated with an increase of 10 percent in moisture deficit). The impact of mode of pricing on the total pumpage is clearly demonstrated by the magnitude and statistical significance of the coefficients of assessed and flat rate pricing variables. The huge shift of water use associated with the assessed flat rate pricing mode is due, in part, to local water use factors associated, but not causally related to the pricing mode (large loss factor and water-extensive industries) in

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[1] For explanation of symbols see footnote 2, p. 76.

two municipalities.

From the magnitude of correlation coefficients shown in Table 32 it is evident that the volume of total pumpage is more dependent on the average expenditure than on the base rate where the coefficients are -0.635 and -0.152, respectively. There is another relationship revealed in this table. Metering is associated with lower volume of total pumpage but also with higher average expenditure; meanwhile, either form of flat pricing has exactly the opposite association with total pumpage and average expenditure.

TABLE 32

JOINT SAMPLE OF MUNICIPALITIES -- TOTAL PUMPAGE (CORRELATION COEFFICIENTS)

(N = 53)

Variable	TP_p	PD	E_u	HS	A_p	BR	MP	AP
PD	0.204							
E_u	-0.635	-0.081						
HS	-0.144	-0.203	0.017					
A_p	0.095	0.082	-0.287	-0.061				
BR	-0.152	-0.124	0.247	0.426	-0.435			
MP	-0.516	0.079	0.517	-0.026	0.065	-0.050		
AP	0.691	0.047	-0.431	-0.088	0.176	0.078	-0.498	
FP	0.061	-0.126	-0.259	0.097	-0.208	-0.003	-0.754	-0.193

For explanation of symbols see notes to Table 30, p. 84.

Conclusion

The main objective of the least squares analysis performed in this chapter was to obtain statistically significant regression coefficients of the variables which were thought to relate to levels of water use. While none of the hypothesized relations are rejected, the empirical data lend only moderate support to some of them due to lack of variance and/or the aggregateness of some of the independent variables and because of imprecision or lack of data (mainly in the case of flat rate pricing municipalities).

There are two important findings which may be singled out:

1) the relevance of unit price of water on either residential use or total pumpage has been indicated;
2) the impact of mode of pricing on levels of water use has been demonstrated.

The results of the theoretical and empirical work presented in this chapter are discussed further and are applied in the chapter on policy implication.

CHAPTER IV

PRICING PRINCIPLES AND PRACTICES IN WATER SUPPLY: THEORY AND ANALYSIS

Nature of Waterworks

The production of treated, piped water is characterized by heavy initial outlays and for this reason, the advantage arising from large-scale production can be fully realized only when a single waterworks is providing water services to a large community. Because of this natural monopoly position of waterworks and the importance of adequate water supplies, these enterprises are either owned by the communities (as is the case of most waterworks in Alberta) or are subject to public utility regulations and operated under what amounts to a fixed profit constraint. Subject to direction by the elected municipal council, a waterworks is free to choose the level of output, mode of pricing and sets of prices which would either earn enough revenue to cover production costs[1] (in the case of public enterprises) or just meet the net revenue constraint (the instance of regulated waterworks). The problem, then, is to determine which of the price-output combinations from the economic standpoint yields the most effective allocation of resources permitted by the above constraints.

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[1] The production costs usually involve operation and maintainance expense, annual debt retirement (cost of interest and amortization payments on outstanding debt), cost of annual capital additions, and taxes or cost of provision of "free" services (such as fire protection) to the community in leiu of taxes.

The Role of Prices

The pricing of water serves different purposes: first, to efficiently allocate production resources to the supply of water in competition with other worthy ends, and to allocate it among users; second, to recover through user charges of some kind the costs incurred in production of tap water. In general, economic efficiency and cost recovering objectives point to different pricing rules which will be discussed presently.

Popular belief regards water as a special good, a necessity of life rather than luxury, and, as such, ought not to be made subject to the ordinary rules regarding optimum resource allocation. On the other hand, it is true that the production and consumption of treated, piped water contains mixed characteristics of both pure private and pure public good because not all the benefits arising from the production and consumption are private in nature. The provision of adequate water supplies is of a public interest as it gives a community control over water borne diseases, helps to upgrade the urban environment and is a basis for fire protection.

Indeed, when a good is a necessity rather than a luxury, it should be a reason for economizing on its use, especially when the abundance of water is more apparent than real and heavy initial outlays in supplying water are involved.

A searching examination of the literature concerned with waterworks rate-making resulted in the following conclusion: At present there is no uniform practice in determining rates. Quite often a rate structure is adopted which would provide sufficient revenue with fewest complaints. Only scant consideration is given to fundamental principles of pricing and very little use is made of cost data and price elasticities of demand.

Even though a number of Alberta municipalities, especially those

served by small scale waterworks, transfer relatively large sums from their tax revenues to cover waterworks costs, there are few, if any, reported instances of a community where user charges were completely replaced by general tax financing.[1] This indicates the preference to recover the costs incurred in water production (at least in part) from those who consume the good.

In the following sections three pricing principles which encompass several of the important objectives of a pricing system will be discussed: 1) the marginal cost rule; 2) average cost pricing; and 3) multipart pricing.

Marginal Cost Pricing

According to the marginal cost rule, resources are efficiently allocated among competing uses when the consumer's satisfaction derived from the last unit of the consumed good is equal to its price, which must equal the real cost incurred by the producer of the last (marginal) unit of the good at the desired quantity level. The rationale is that consumers of any product are paying for it in an amount exactly equal to the value of the resources used up in producing the last unit of it. Had these resources been diverted to another industry, they would have yielded a product of the same value provided they are priced at marginal cost too. When all prices in the economy are set in this manner, it will lead to a pattern of output which simultaneously takes into account the relative scarcity of resources and the pattern of consumer preference. In this perfectly

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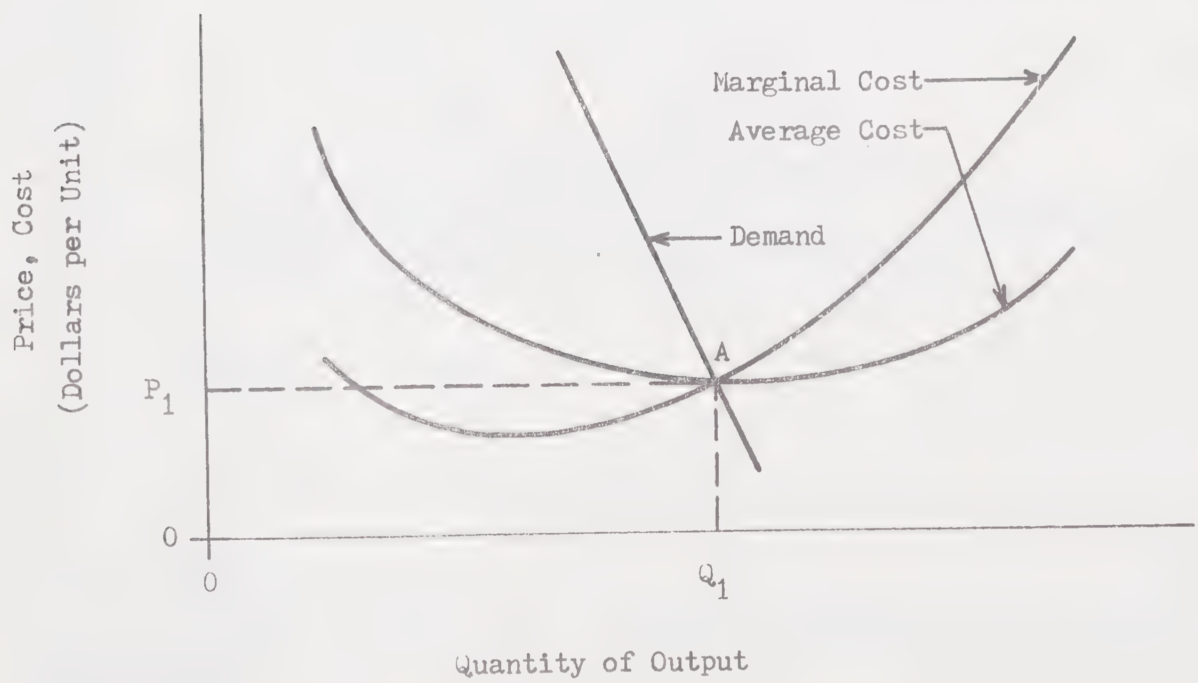
[1] The financial situation of Alberta waterworks is discussed in detail in Chapter II of this study.

competitive situation and in the absence of externalities, both in production and consumption, if a price of the good (as determined by demand and supply conditions) fails to cover marginal cost, consumers are paying too little for the provision of the good, which has been over supplied. On the other hand, the price in excess of marginal cost is an indication of unduly constrained demand.

In order to attain an equilibrium situation in production, a price of the good should cover not only marginal cost but also average cost which enables the enterprise to "break even" so that the enitre cost of production is being placed on the consumer. Such a situation is illustrated in Figure 5 where the demand curve D cuts the average cost curve AC at its lowest point A; that is, where the marginal cost equals the average cost.

FIGURE 5

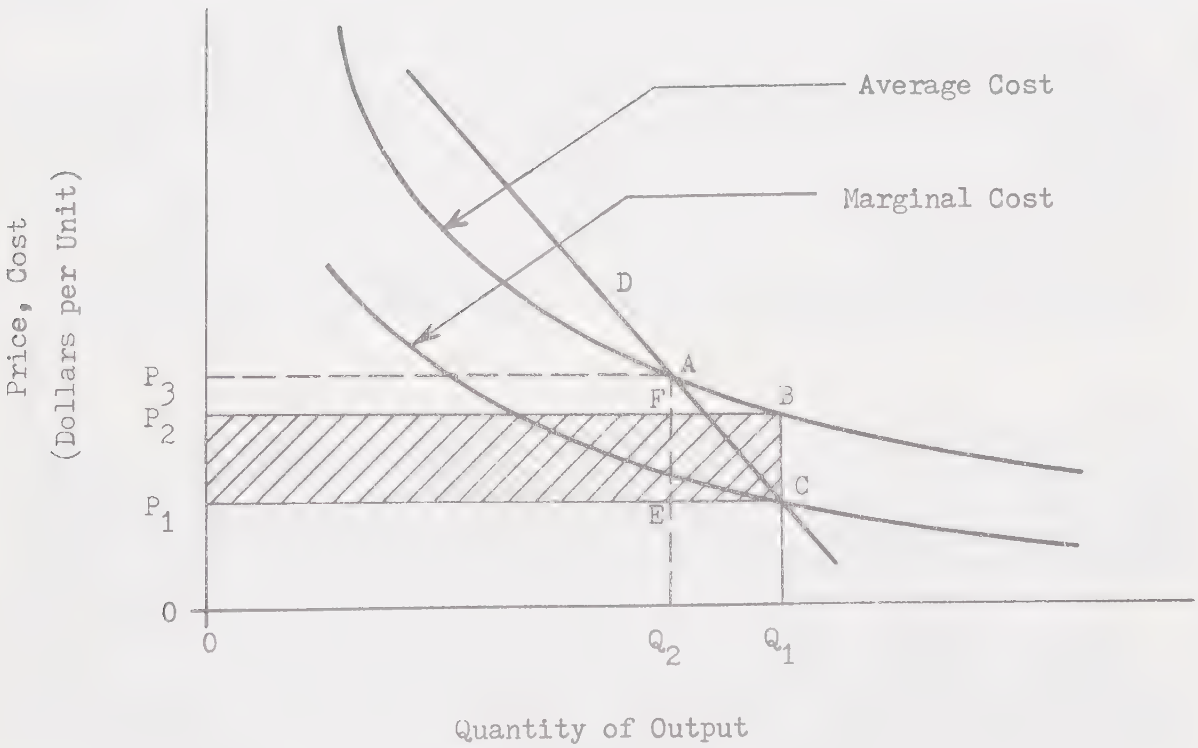
MARGINAL COST PRICING (P = MC = AC)



A problem arises when the producer is operating under conditions of increasing returns to scale, i.e. decreasing costs, as is often the case with waterworks.[1] This situation is caused by the increase in technical efficiency as a result of expansion of treatment plant and/or distribution capacity. Under these conditions, the producer will incur a loss if he prices water equal to the marginal cost in order to attain socially optimal allocation. In this case, the price fails to cover the average cost (Figure 6).

FIGURE 6

MARGINAL COST PRICING UNDER INCREASING RETURNS TO SCALE



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[1] This assertion is based upon the empirical evidence given in Chapter II of this study.

The consumers will demand more units of the good up to OQ_1 where price P_1 is a measure of the satisfaction foregone for not consuming other goods. However, with output OQ_1 at the price P_1, the producer encounters a revenue loss to the extent of the shaded rectangle P_1CBP_2, which amounts to a subsidization of the consumer (the loss, in the case of a publicly owned waterworks, would have to be covered by transfers from general taxation revenues). On the other hand, if the producer decides to cover his expenses by setting the price at P_3, the output demand at this price would be reduced to OQ_2, corresponding to a net loss in society's surplus[1] and represented approximately by the area AEC.[2]

A strict adherence to this pricing rule would imply that all buyers be faced with a single marginal price, therefore block prices are inconsistent with this pricing rule.

The marginal pricing rule, however, cannot be recommended without some reservation. First, marginal cost pricing will achieve an optimal resource allocation only in the world of pure competition where social and private costs and benefits will need to be equal throughout the economy so that if each person of society pursues his own aims, he necessarily promotes

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[1] Goods, in general, are valued, not according to their real uses in supplying the necessities of men, but rather in proportion to the effort (in terms of labour and capital) that is required to produce them. The excess of price which the consumer would be willing to pay rather than go without the good, over that which he actually does pay is the economic measure of the surplus satisfaction called consumer's surplus.

[2] It appears that a clear distinction has to be drawn between the water user's surplus, the producer's (waterworks') surplus, and society's or net social surplus, which is the sum of the two. The shift in price from P_1 to P_3 costs the water user dearly, since he loses all the "subsidy" P_1CBP_2. Therefore, total water user's surplus "lost" by the price charge is the area ACP_1P_3. Producer's surplus gained due to the price increase is the area $ABCP_1P_3$. The difference between these two seems to be represented only very approximately by the triangle ACE. Total social loss then is: ACE - (AFP_2P_3 - BCEF).

those of the rest of the community as well. Unfortunately, both the above conditions are partly violated in the water supply industry because waterworks are natural monopolies and benefits which accrue from adequate water supplies cannot be fully divisible to the individual consumer. Second, if the waterworks' average costs decrease when the scale of its production increases (increasing returns), and the enterprise sells at a unit price equal to marginal cost, the enterprise must lose money on each and every unit it sells, no matter how efficient its operations. If the deficits are to be made up by a subsidy out of taxes, these funds have to be derived by making some other prices depart from marginal costs. Third, the marginal cost rule is based on the assumption that the marginal utility of money is equal to all consumers, because they are paying the same price for the good. To agree with this proposition in effect implies that optimal resource allocation is a function of ability to pay for the product, rather than a function of the distribution of social satisfaction.

Even if these qualifications prevented the marginal cost rule from governing rates, it is useful because it helps to determine whether additional waterworks output justifies a community's foregoing other goods.

Average Cost Pricing

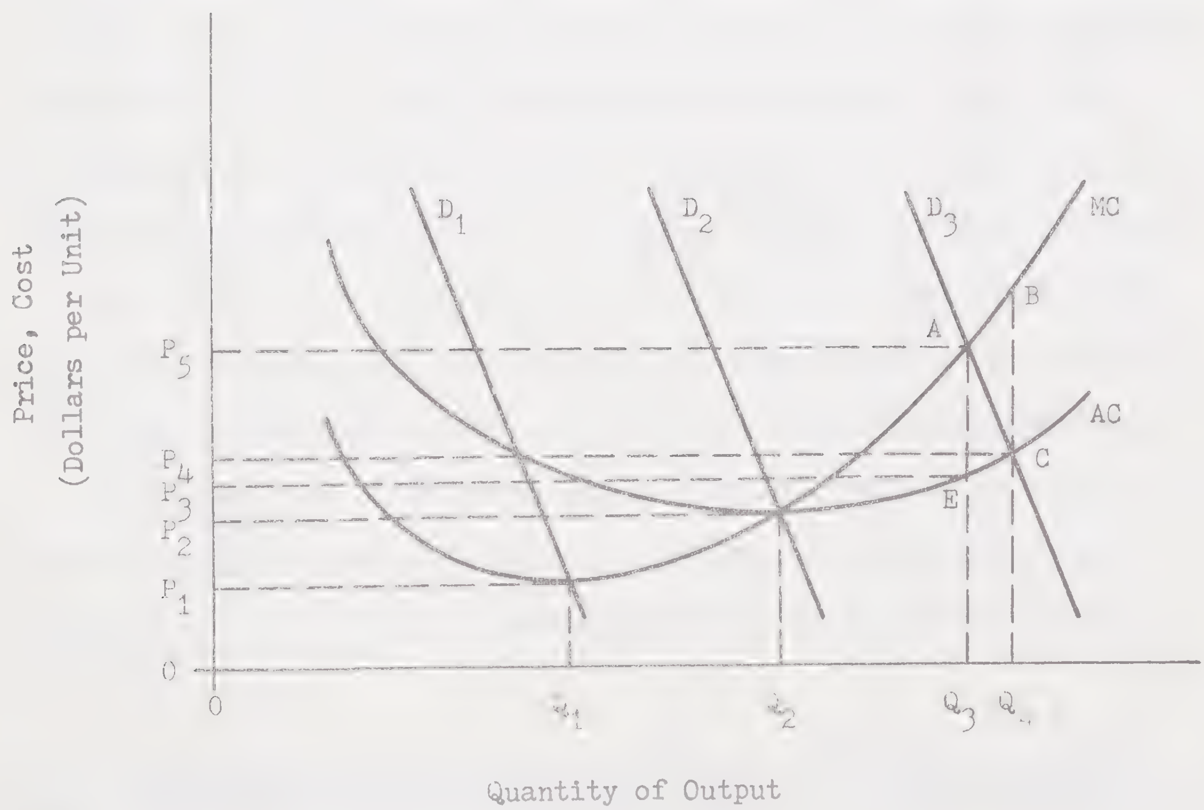
When the goal of an enterprise is to be self-supporting, i.e., the rates are set at such a level as to gather enough revenue to cover the full cost of production, then the average cost pricing will ensure the achievment of the objective. The average cost principle gives an impression of fairness because consumers are asked to pay according to the value, on the average, of the resources used up on their behalf so that the producer neither makes a profit when marginal costs exceed unit costs nor

subsidizes consumers in the case of decreasing average costs.

This form of pricing, however, does not guarantee that the allocation of resources will be socially optimal. The magnitude of potential resource misallocation will depend on the conditions of cost and demand as shown in Figure 7. Generally, the misallocation will be smaller the closer marginal cost approximates average cost. When marginal cost is equal to average cost, the indicated output OQ_3 is socially optimal under both rules. Also, resource misallocation will be small when the price elasticity of demand is low, i.e., the rate of water use is affected only a little by changes in water rates.

FIGURE 7

AVERAGE AND MARGINAL COST PRICING



The inadequacy of the objective of just covering costs with revenues is demonstrated in Figure 7 in which marginal and average cost pricing are contrasted. In this diagram, average costs decline in the range of output OQ_2 and then rise after production is continued beyond this point.[1]

If the waterworks practiced average cost pricing in the range of increasing average costs (i.e., facing D_3), it would produce OQ_4 units of water at a price level OP_4 and no financial surplus would be realized. It can be noticed, however, that the marginal cost incurred in producing the OQ_4th unit exceeds the demand price OP_4 by BC. Since consumers' valuation of output beyond the socially optimal output level OQ_3 is lower than the actual cost, it indicates that the resources would be employed to a greater advantage in some other industry where consumers could get more benefit from them to the extent of the area ABC. The average cost pricing in this case would thus lead to over-utilization of production capacities as a result of under-valuation of scarce resources. In theoretical terms, the amount of social loss is measured by the area ABC. On the other hand, pricing according to marginal cost rule would establish a rate level of OP_5 followed by the socially optimal output OQ_3. In this case, total revenues would exceed total costs and a surplus of P_3EAP_5 would be realized.

Only in the case where marginal and average costs are equal (i.e., demand D_2), setting a rate level at OP_2 would have resulted at a socially optimal production level of OQ_2 and in the waterworks's breaking even.

In summary, the adherence to the average cost pricing rule will ensure the waterworks, at any production level, with generating enough revenue to balance production expenditures. At the same time, there is

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[1] For a discussion regarding the implication of pricing policy on the range of decreasing average costs (i.e., demand D_1) see the previous section.

likely to be some degree of resource misallocation which can be empirically determined through knowledge of demand and supply conditions for the product in question.

A Suggested Water Rate Schedule: Multipart Pricing

There are three main criteria which should be integrated into a system of charging for water services such that:

1) water users pay the share of costs that is attributable to their own actions;
2) water users are free to determine the quantity of water taken and time of use, and thereby control the amount of their monthly water bill;
3) the system of billing and enforcing is workable and of reasonable cost.

It has been pointed out earlier that the waterworks faces a demand for water which is unevenly distributed over the seasons of the year. For this reason a good pricing policy should also account for the differences in the load factor[1] of the individual water users. It means that the price of water should cover not only the marginal cost per unit of water but also reflect the capacity cost (a cost related to capital and maintenance costs of the system), i.e. the marginal cost per unit of capacity required to provide the water at a time as specified by the user. The rate attributable to a demand-for-capacity is characterized by the ratio of peak to average demand and the duration of the peak de-

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[1] The customer's load factor is his average water usage expressed as a percentage of his maximum water use.

mand. This pricing argument is based upon the Williamson's[1] method which separates demand-for-quantity from demand-for-capacity and blends the rate such that the cost of the marginal quantity, (the operating cost) as well as the cost of the marginal capacity (the capital and maintenance costs) are covered. While the operating cost (b) remains the same for any period, the capacity cost (c) is a variable and depends, in effect, upon the demand-for-capacity. For any portion of the demand cycle (w_d) with a given demand-for-capacity the price to charge equals:

$$P_d = b + c_d/w_d$$

The second part of the rate (c_d/w_d) increases with the peak-to-average use ratio, and decreases the longer the fraction of the demand cycle is during which load d prevails.

Using Williamson's method and assuming that waterworks revenues should cover its costs it will become necessary to separate rates into the charge for quantity (b) which is uniform to all users, and the charge to cover the cost satisfying the users' demand-for-capacity. There are basically two methods to determine the user's demand-for-capacity. Assuming that monthly peak demands are related to possession of observable water using installations such as lot or garden area, home value, washing machines, bathtubs and showers, etc., then this information can be used to assign to the user a demand-for-capacity rate. This assessment will be done only once at the commencement of the service and re-assessment will be warranted only when the installations are changed. A similar procedure is already

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[1] O.E. Williamson, "Peak-Load Pricing and Optimal Capacity Under Indivisibility Constraints," American Economic Review, Vol. 56, (1966), pp. 810-827.

used to determine assessed flat rates for water use in several Alberta communities. This method will be suitable for smaller waterworks with manual billing procedures.

More equitable will be an alternative method which bases the demand-for-capacity rate on the ratio of the user's own annual average use and the average daily use per billing period. The necessary calculations can be readily performed by a computerized billing routine.

Employing either of the methods described above will not require an installation of dual-rate meters to be timed for peak and off-peak use and will also prevent penalizing those users with fairly stable water demands throughout the year.

The portion of capital and maintenance costs attributable to provision of fire protection services, irrigation of public parks, etc., can be covered by special frontage taxes or general property taxation. On the other hand, the cost of "beautification" will be the capital and maintenance cost of the additional readiness-to-serve system capacity to provide the extra irrigation water which users will not otherwise be willing to buy for their own satisfaction. Thus, a general revenue transfer to the waterworks will enable it to reduce the demand-for-capacity charge to individual users accordingly.

As a result of such a pricing policy, a revenue surplus will be produced when a waterworks operates under increasing costs. The surplus, in the case of a regulated waterworks may either be subjected to some form of municipal taxes, or the rate of the first units of water may be reduced, which would notably assist low income customers, enabling them to afford more readily that water considered indispensable for satisfying vital sanitary requirements. The extra revenue, in the case of municipally-owned waterworks, could be used either as a source of funds to meet further

capital outlays in water and sewage sustems or may be used to alleviate adverse effects of relatively higher rates on low income customers in the manner described above, i.e., by reducing prices on the first units of water.

A problem may arise, however, in defining whose interests the waterworks serve by expansion of production capacity. When the economies of scale are realized as a result of expansion, the strict adherence to the multipart pricing principle would require that the new users should be charged a lower rate than the existing users. If the objective of the waterworks is to minimize costs for existing consumers, however, the savings will be passed along to existing users by charging a lower rate for all users. Under increasing cost conditions the waterworks, acting in the interest of the existing consumers, should charge these new users a higher price to reflect the full cost of the expansion; i.e., assess these differential production costs on the direct beneficiaries.[1]

Multipart pricing is sufficiently flexible and capable of achieving efficient and equitable allocation of costs and benefits stemming from provision of water. Furthermore, a review of Alberta's waterworks pricing practices (pp. 21 to 27) suggests that multipart pricing is a consideration in setting the water rates. Only a refinement of current rate setting practices will be needed in order that community benefit may be maximized.

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[1] One would expect that expanding the service area (as through new subdivisions) would increase average costs, while increasing settlement density or increasing water delivery within an established area would reduce the average cost of providing water.

The City of Edmonton has begun to charge developers for the cost of installing not only water lines on residential streets, but for the full cost of extending water mains to new subdivisions. Since the developers pass this cost to home buyers, it becomes another part of pricing waterworks services.

It has been noted earlier that for a satisfactory examination of pricing principles and practices, an empirical analysis of demand and cost conditions is required. Since the demand for water by Alberta municipalities has been the topic discussed in the previous chapter, the following section will be on analyzing cost relations in water supply.

Analysis of Cost Data

Factors Affecting Water Cost

The production of treated, piped water consists of: a) selecting the source which may be surface (lakes, rivers, reservoirs, irrigation canals, etc.), underground (wells), or a combination of the two; b) conveyance of water to the processing plant; c) treating the water to make it suitable for human consumption; d) storage and distribution of treated water to municipal customers.

The number and type of treatment process, such as disinfection, sedimentation, coagulation, softening, aeration, absorption, chemical oxydation, filtration, fluoridation and stabilization, to which water is subjected depends on the quality of the intake water. In general, surface sources yield a lower overall quality of input water than ground sources and thus result in higher processing costs.

Costs incurred in provision of water are comprised of fixed and variable factors. Fixed costs are the per period opportunity and depreciation costs of capital and administrative costs, such as billing, metering costs and capital additions and/or improvements. Variable costs include such cost items that vary in proportion with the quantity of water withdrawn by consumers, i.e., wages, chemical costs, electricity and costs of con-

veyance. Total costs are the sum of fixed and variable cost components which vary either with time or output level of the waterworks. According to the accounting practices of some waterworks, "total expenditure" includes such other expenditures as local taxes, etc. For purposes of this study, these additional items were excluded from the data showing total costs, average total costs (i.e., total costs divided by the quantity of water produced) and marginal costs (that is, the cost incurred from production of an additional unit of output).

The factors assumed to affect significantly unit costs of waterworks output are: 1) scale of production measured as an output per annum; 2) mode of pricing, i.e., whether metering costs are involved; and 3) source of water, mainly through its impact on quality of intake water. The area serviced by a waterworks may be also of importance because it affects the amount of capital opportunity and depreciation costs and the cost of capital additions.

The Hypothesized Functional Relationship

The functional relationships describing water supply costs for the entire community in terms of the parameters in the model may be expressed as:

$$ATC = f(AP, PL, AR, MP, IC, LK, RS, RV, OS) \tag{12}$$

The linear regression relationship may be written:

$$ATC = a_0 + a_1AP + a_2PL + a_3AR + a_4MP + a_5IC + a_6LK + a_7RS + a_8RV + a_9OS + U \tag{13}$$

where:

$a_{0,1...9}$ are the regression coefficients (although a_0 is usually termed the intercept, or constant term);

ATC is the average total cost per 100 cubic meters in dollars per year;

AP is the total pumpage in cubic meters per person served per year;

PL is the common logarithm of the total population served by the waterworks;

AR is equal to one only for municipalities which have assessed flat rate pricing;

MP is equal to one only for municipalities which have metered pricing;

AR and MP are zero-one dummy variables of mode of pricing, where a criterion which is met is scored one and otherwise zero;

IC is equal to one only for waterworks processing water from irrigation canals;

LK is equal to one only for waterworks processing water from lakes;

RS is equal to one only for waterworks processing water from reservoirs;

RV is equal to one only for waterworks processing water from rivers;

OS is equal to one only for municipalities utilizing other than the above sources of water;

IC, LK, RS, RV, and OS are zero-one dummy variables of a primary source of water where a criterion which is met is scored one and otherwise zero (note that waterworks obtaining water from wells are identified by a zero value);

U is the error of the equation having the usual stochastic characteristics.

Since there are no *a priori* reasons indicating whether the functional

form of the relationship will be linear or multiplicative, both forms will be examined and the equation which best fits the sample data will be selected. The magnitude of the regression coefficients estimated by the method of least squares cannot be predetermined ex ante; however, the sign of the coefficients of AP and PL is expected to be negative, signifying economies of scale. In the case of dummy variables, the magnitude and algebraic sign will also be influenced by the selection of a variable serving as a base. For example, when flat rate pricing acts as a base, the sign of AR and MP can be expected to be positive and the magnitude of MP to be greater than AR, meaning that flat rate pricing is the least costly method of administering water rates, followed by assessed flat rate pricing, while the most costly method is metered pricing. A similar reasoning may be applied in the case of different sources of water where the utilization of underground water may be shown to be the least costly source.

Estimated Cost Function

This section presents an estimate of cost function using adjusted annual expenditure data for 102 Alberta municipalities in the sample.[1] Table 33 shows the means, standard deviations and coefficients of variation of the sample data. The relatively high values of the coefficient of variation for total pumpage per person and the average total cost per 100 cubic meters of output reflect the presence of large and small scale waterworks in the sample. There are 66 municipalities metering their resi-

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[1] In fact, all the data required by the estimating equation were secured for only 51 municipalities, but they were complete for both studied years. The preference has been given to combine the two years observation to one sample rather than using the averages of the two years 1966 and 1967.

TABLE 33

JOINT SAMPLE OF MUNICIPALITIES -- AVERAGE TOTAL COST

(N = 102)

Variable	Mean Value	Standard Deviation	Coefficient of Variation
ATC	18.076	10.630	58.81
AP	154.168	108.940	70.66
PL	3.492	0.560	16.04

Note: ATC is the average total cost per 100 cubic meters in dollars;

AP is the total pumpage in cubic meters per person served per year;

PL is the total population served by the waterworks in logarithm to base 10.

dential customers in the sample. From the remaining 36 municipalities, 25 communities are using flat rate pricing and 11 communities charge their residential customers assessed flat rates. By source, 42 communities obtain water from rivers, 32 communities from underground sources (wells), 10 communities from irrigation canals, 10 communities from lakes, 6 communities from reservoirs, and 2 communities depend on other sources for their water needs.

In Table 34 the matrix of correlation coefficients of variables tested by the estimating equation (12) is presented. The negative algebraic signs and the magnitude of the correlation coefficients clearly demonstrate the impact of large scale production on the average cost.

TABLE 34

JOINT SAMPLE OF MUNICIPALITIES — AVERAGE TOTAL COST (CORRELATION COEFFICIENTS)

(N = 102)

Variable	ATC	PL	AP	RV	IC	RS	LK	OS	AR	MP
PL	-0.286									
AP	-0.624	0.100								
RV	-0.100	0.453	0.324							
IC	-0.202	-0.144	0.138	-0.276						
RS	0.452	-0.146	-0.153	-0.210	-0.082					
LK	0.038	-0.142	-0.128	-0.276	-0.109	-0.082				
OS	-0.044	-0.088	-0.010	-0.118	-0.047	-0.035	-0.047			
AR	-0.414	-0.279	0.686	0.416	-0.115	-0.087	-0.115	-0.049		
MP	0.517	0.065	-0.524	-0.216	0.106	0.185	0.106	-0.191	-0.471	
FF	-0.276	-0.273	0.087	-0.060	-0.035	-0.142	-0.035	0.248	-0.198	-0.701

Note: For explanation of symbols see note to equations (12) and (13), p. 101.

On the other hand, in municipalities employing metering and/or depending on reservoirs for their water, the average costs are likely to be high.

When the theoretical equation (12) (p. 103) assumed to "explain" the variation in the average total cost, has been subjected to least squares analysis, the following linear equation of "best fit" is secured:

$$ATC = 43.536^{**} - 7.604PL^{**} - 0.050AP^{**} + 7.731MP^{**} + 3.149AR + 14.518RS^{**} +$$

standard errors: 4.595 1.298 0.009 1.647 2.985 2.780

$$+ 6.999RV^{**} + 2.511OS - 3.487IC^{o} - 0.089LK^{1} \qquad (14)$$

standard errors: 1.647 4.571 2.370 2.225

$R^2 = 0.70$ F-value $= 24.14^{**}$ N = 102

In the above equation, the flat rate pricing serves as a base for investigation of pricing methods, and wells are the base from which to evaluate the contribution of different primary sources of water to the average total cost of production. The explained variation in the average total cost is 0.70 and all major variables in the equation have coefficients significantly different from zero at high probability levels. The magnitude of the intercept (43.536) indicates the presence of a rather large fixed component of total costs. Negative algebraic signs and magnitudes of variables PL and AP signify presence of economies of

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[1] For explanation of symbols, see footnote 2, p. 76.

scale in the above equation.[1] In the next section, where marginal costs will be calculated, this tentative assertion may be stated with more confidence.

When the impact of mode of pricing on the average total cost is evaluated, both varieties of flat rate pricing contribute less to waterworks costs than metering does, ceteris paribus. This finding may be of importance to waterworks managers especially in the case of abundant water supplies associated with low unit costs.

It appears that, other things being equal, ground water sources and lakes prove to be less costly to exploit than water from reservoirs, rivers or other sources. Waterworks drawing their water from irrigation canals have lower costs than those drawing from wells.

Derivation of the Marginal Cost Curve: An Illustration

On several occasions the results of the analysis of Alberta waterworks expenditure data have suggested the presence of economies of scale in the industry. It is the object of this section to determine the relationship between the output of a hypothetical waterworks, as characterized by its gross pumpage, and a corresponding marginal cost. The following analysis is based on equation (14), stating the average total cost relationship. For illustrative purposes, it is assumed that the waterworks in question employs metering and drew its water from a river. Then, equation (14) becomes:

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[1] The variables PL and AP form an identity where: Gross waterworks pumpage (TP) = Population served (10^{PL}) x Total pumpage per person served (AP).

$$ATC = 43.536 - 7.604PL - 0.050AP + 7.731MP + 6.999RV \qquad (15)$$

where:

- MP is equal to one (case of metering);
- RV is equal to one (case of pumping water from rivers);
- AP is the total pumpage in cubic meters per person served per year;
- PL is the total population served by the waterworks in logarithm to base 10.

After collecting terms:

$$ATC = 58.266 - 7.604PL - 0.050AP \qquad (16)$$

It is realized that the total pumpage (or TP) is not independent of a community size as expressed by the number of residents. For this reason, marginal cost will be determined for the two cost-related variables which have been isolated in the previous section: population (PL) and pumpage per person (AP). The marginal cost, with respect to changes in population, is of the nature of a "long-run" cost curve since it is measured against the entire cross section of municipalities (with different waterworks plants and capacities and settlement lay-outs which together determine cost factors that are subject to change only by investment, and possible only during considerable periods of time).

On the other hand, the change in costs (marginal and average) resulting from a change in per person pumpage (AP) might be considered as an approximation of a short-run cost curve.

The following are the calculations of: 1) marginal cost function

reflecting changes in population, and 2) marginal cost function reflecting changes in per person pumpages.

I. $$ATC = a_0 - b_1 \log_{10} P - b_2 AP \qquad (16a)$$

Because marginal cost can be calculated directly only from a total cost function, the above equation will be multiplied by the waterworks total pumpage TP = AP x P:

$$TC = a_0 AP \times P - b_1 AP \times P\log_{10} P - b_2 AP^2 \times P \qquad (17)$$

The partial derivative of the above equation with respect to P (holding AP constant at various levels) generates the following equation:

$$dTC/dP = MC_P = AP((a_0 - (b_1 \log_{10} P + b_1 P/\ln 10 \times 1/P) - b_2 AP)) \qquad (18)$$

or:

$$dTC/dP = MC_P = AP(a_0 - b_1/\ln 10 - b_1 \log_{10} P - b_2 AP) \qquad (19)$$

Dividing the above equation by AP, the MC_P function in terms of dollars per 100 cubic meters can be obtained:

$$MC_P = a_0 - b_1 \times 0.4343 - b_1 \log_{10} P - b_2 AP \qquad (20)$$

By substituting the values from equation (16) into equation (20) and collecting terms, the following marginal cost equation with respect to population is obtained:

$$MC_P\ (\$/100m^3) = 54.964 - 7.604PL - 0.050AP \tag{21}$$

II. The partial derivate of equation (17) with respect to average pumpage per person (AP) when holding population (PL) constant at various levels generates the following equation:

$$dTC/dAC = MC_{AP} = a_0P - b_1PL \times P - 2b_2AP \times P \tag{22}$$

Dividing the above equation (20) by P and substituting the values from equation (16) the following marginal cost equation with respect to average pumpage in terms of dollars per 100 cubic meters is obtained:

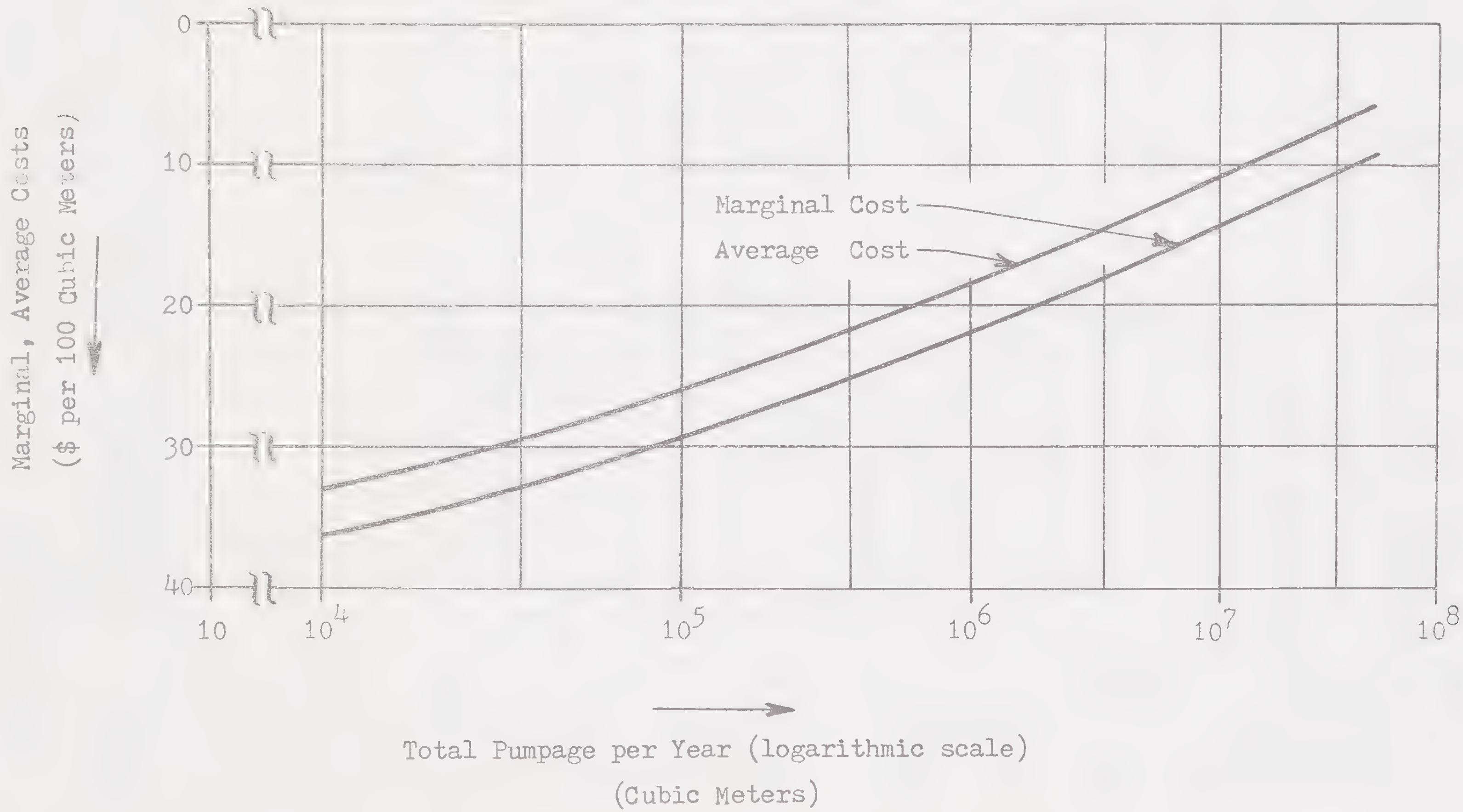
$$MC_{AP}\ (\$/100m^3) = 58.266 - 7.604PL - 0.1AP \tag{23}$$

When the mean values of PL and AP, as given in Table 33, are substituted into equations (16) and (21) it becomes obvious that the hypothetical waterworks operates under decreasing cost conditions because the average cost at that output level is equal to \$ 24.04 per 100 cubic meters while the "long-run" marginal cost is only \$ 20.70 per 100 cubic meters. In Figure 8 the relationship between "long-run" marginal and average costs and a corresponding total pumpage of the waterworks is demonstrated. The diagram is based on the assumption that there is no fluctuation in the average pumpage per person per year as a result of changes in total output level. Levels of output, as stated in the diagram, correspond to a particular size of municipality characteristic in a Alberta situation. The diagram clearly demonstrates that the hypothetical waterworks operates under a decreasing cost situation throughout the relevant range of production.

FIGURE 8

STRUCTURAL RELATIONSHIP BETWEEN "LONG-RUN" MARGINAL AND AVERAGE COSTS AND THE LEVEL OF OUTPUT

(AP = 154.164 Cubic Meters per Year)



The fluctuation of total pumpage per person in relation to municipal size is shown in Table 35 based on 1966-1967 data and equation (23). Municipalities have been divided into six size groups, according to population size. This division very closely approximates different sizes of waterworks, assuming that the sale of water outside the corporate limits is not significant. The terms "-SD" and "+SD" represent the fluctuation of one standard deviation around the mean value of the total pumpage per person for a particular size group. The data in Table 35 demonstrate the effect of per person pumpage upon marginal costs for a given population.

Figure 9 shows a family of short-run marginal curves[1] for different sizes of waterworks. For each level of output the coefficient of cost elasticity has been calculated.[2] The value of the coefficient provides an indication of the responsiveness of cost to changes in the output level. It is the measure of relative cost change for a given change in output value. Elasticity of one indicates an equiproportionate change. Zero elasticity suggests that costs will not respond to further increases in output. According to the cost and elasticity data given in Figure 9, not only is marginal cost strongly influenced by the waterworks volume of output, but also the capability of reducing the impact of output changes on cost is dependent on waterworks size.

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[1] The "short-run" cost curves (Figure 9) are not conventional short-run curves. They can be defined as expressing the change in unit cost induced by a change in per person pumpage (AP) for a given population.

[2] The mathematical formula on which the calculation of point-cost elasticities is based is as follows:

$$E_c = MC/AC$$

TABLE 35

PUMPAGE AND "SHORT-RUN" MARGINAL COST ESTIMATES FOR DIFFERENT SIZES OF MUNICIPALITIES, ALBERTA, 1966-1967

Characteristics		Measurement Unit	Population Range					
			<500	501-1,000	1,001-3,000	3,001-10,000	10,001-100,000	>100,000
Community Size (average)		Person	278	794	1,874	4,615	25,169	358,865
Average Pumpage per Person per Year	-SD	m^3/person/year	22.062	43.398	28.126	71.389	69.742	137.810
	average		103.426	99.529	149.062	105.792	193.754	187.144
	+SD		184.790	155.660	269.998	140.195	317.766	236.478
"Short-Run" Marginal Cost	-SD	dollars per 100 m^3	21.19	20.64	6.38	16.38	*	*
	average		29.33	26.26	18.47	19.82	5.44	*
	+SD		37.47	31.88	30.56	23.26	17.84	2.25

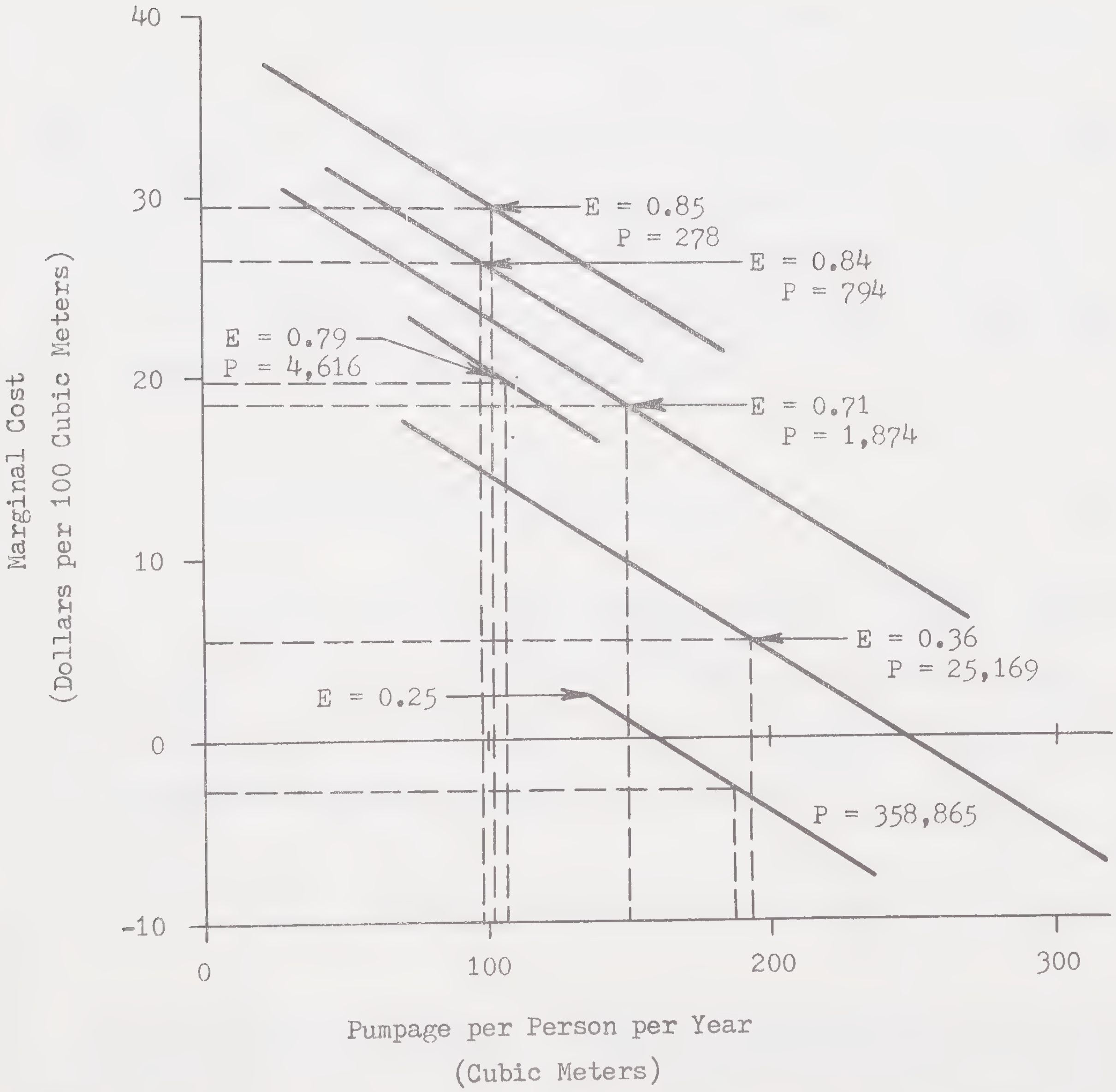
Notes: The terms "-SD" and "+SD" represent the fluctuation of one standard deviation around the mean.

* Negative values are obtained leaving the "Short-Run" Marginal Cost values indeterminate.

FIGURE 9

SHORT-RUN MARGINAL COST CURVES FOR WATERWORKS OF DIFFERENT OUTPUT LEVELS, ALBERTA, 1966-1967

(The length of each marginal cost curve represents the range of ± one std. deviation around the mean value of AP.)



Waterworks Price-Quantity Combination

In this section the "long-run" marginal cost function (21) will be discussed in relation to the demand function (11) which is also derived from data relevant to Alberta waterworks. For reasons of comparability, it will be assumed that the hypothetical waterworks are utilizing a river as a primary source of water and employ metering. Thus, the demand estimating equation becomes:

$$D = AP = 187.068 + 0.272PD - 17.759HS - 3.782E_u \qquad (24)$$

When the values of variables representing precipitation deficit (PD) and household size (HS) are set to their sample averages (i.e., 259.24 and 3.77, respectively, as shown in Table 31, p. 85), then the expenditure per 100 cubic meters (E_u), which is a substitute for price, becomes the main determining factor of the quantity demand.

$$AP = 190.63 - 3.782\ E_u \qquad (25)$$

In the marginal cost estimating equation (21), the variable of population size will be set to different values which are relevant in the Alberta context. This procedure will enable the estimation of marginal cost data for various output levels.

$$MC_P\ (\$/100m^3) = 54.964 - 7.604PL - 0.05AP \qquad (26)$$

Solving the demand and cost equations simultaneously, the price and output combination at which demand and cost curves cross each other can

be determined. Following is an example of calculations involved in determination of the equilibrium price-quantity combination where the price of water is set to its long-run marginal cost.

$$\text{Demand: } AP = a_0 - b_1P \tag{27}$$

where:

P is price.

$$\text{Supply}^{1}\text{: } P = MC = a_1 - b_2AP \tag{28}$$

(case of decreasing costs).

Step 1: Rearranging the terms:

$$a_0 = AP + b_1P \qquad / \times b_2 \tag{29}$$

$$a_1 = b_2AP + P \tag{30}$$

Step 2: Multiplying equation (29) by the coefficient b_2:

$$a_0b_2 = b_2AP + b_1b_2P \tag{31}$$

$$a_1 = b_2AP + P \qquad (-) \tag{32}$$

Step 3: Subtracting equation (32) from equation (31) and solving for price (P):

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[1] It is assumed that the marginal cost function also represents waterworks' supply function, i.e., it summarizes waterworks quantity reaction to various prices.

$$a_1 - a_0 b_2 = (1 - b_1 b_2) P \tag{33}$$

$$P = \frac{a_1 - a_0 b_2}{1 - b_1 b_2} = c \tag{34}$$

Step 4: Substituting the value of price (P = c) secured above into equation (27) and solving for average pumpage per person (AP):

$$AP = a_0 - b_1 c = d \tag{35}$$

In Figure 10 the equilibrium price-quantity points for different populations are shown. At each such point, the price of water is set at its long-run marginal cost. This price, on the other hand, also expresses the consumers' valuation of the output which is at its socially optimal level. Since marginal cost equation (21) represents a decreasing cost situation where marginal cost is lower than the unit cost (see Figures 6 and 7, pp. 93 and 96), the waterworks will incur a loss by charging the price just equal to marginal cost. The inclusion of some form of assessed charge reflecting the differences in the load factor[1] of the individual water users would then ensure not only covering all costs by price but would also assure the greatest possible compliance with an economically efficient resource allocation.

The presence of significant economies of scale in the industry also explains why many small municipalities find it financially advantageous to purchase water from large-output waterworks despite water rates which

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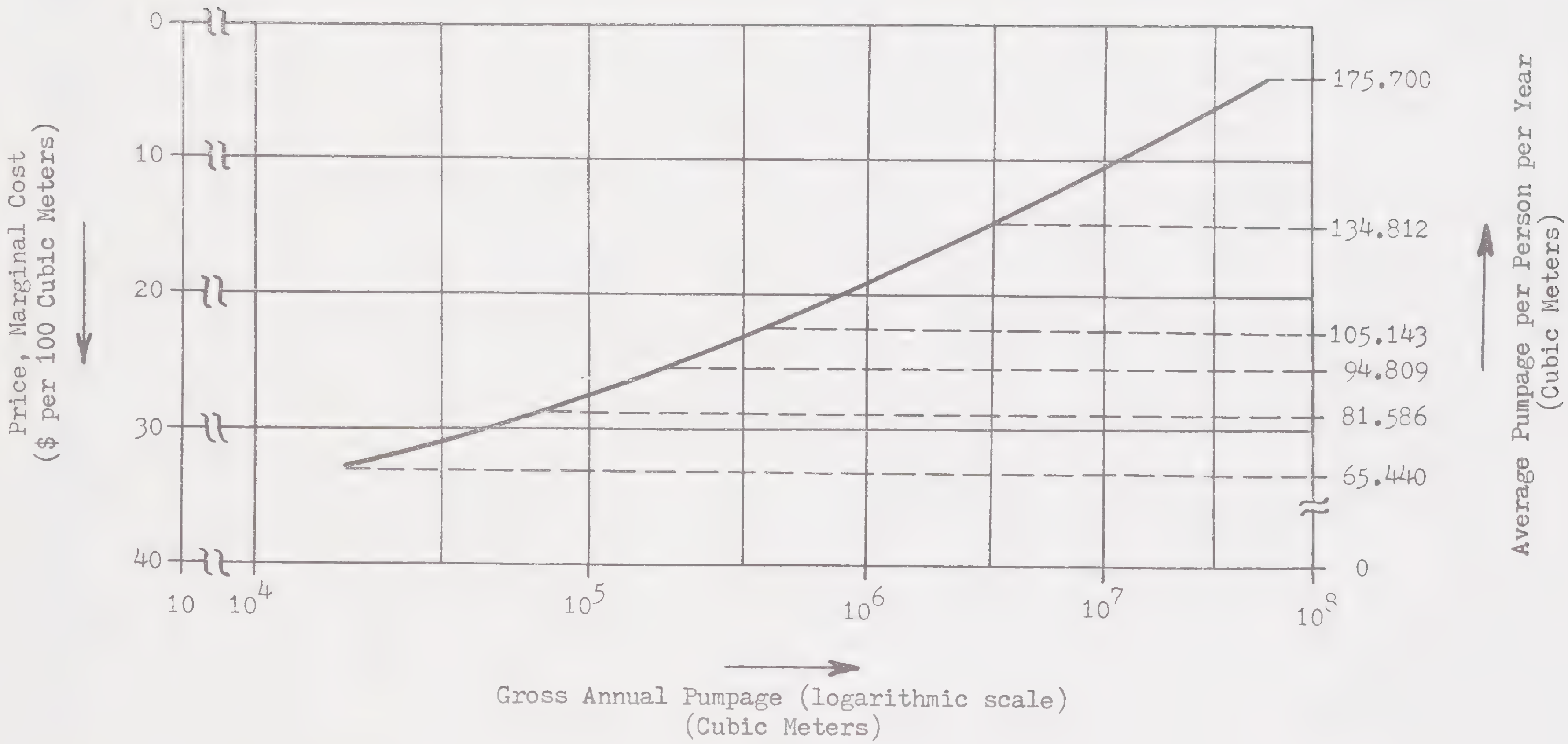
[1] For more detailed discussion on this topic see pp. 98-102.

FIGURE 10

EQUILIBRIUM PRICE -- OUTPUT COMBINATION

(Price = "Long-Run" Marginal Cost)



include a surcharge of up to 35 percent.[1]

[1] The City of Edmonton sells over 10 percent of its annual pumpage to a number of surrounding municipalities for a price which includes a surcharge of 35 percent.

CHAPTER V

SUMMARY AND CONCLUSIONS

Analysis of Alberta waterworks pumpage data, water purchase data by major classes of municipal waterworks customers, and data on waterworks revenues and expenditures has made possible a number of conclusions regarding the nature of demand for water, cost relations in water supply, pricing policy, and the direction of future investigations.

1) In 1967, municipal waterworks provided treated, piped water to more than 70 percent of the total Alberta population, i.e., to 98.2 percent of municipal residents residing in 315 municipalities throughout the province. The southwestern and northern regions of central Alberta show the main concentration of municipal population depending on rivers for their water needs. However, the majority of small-scale waterworks utilized underground sources of water. It is estimated that the annual withdrawal of water by all Alberta waterworks in 1967 was over 186 million cubic meters. On the average, 56 percent of waterworks gross pumpage is for residential use, 34 percent is for commercial and industrial uses, and the remaining 10 percent is for public and other uses. The percentage distribution of gross pumpage is strongly influenced by the size of the municipality expressing the concentration of large commercial and industrial users.

2) Community water demand is greatly affected not only by absolute numbers of customers in each user class, but also by the mode of pricing, i.e., whether water consumption by customers is metered or not. It appears that the annual gross pumpage per person in flat rate pricing municipalities exceeds that in metered municipalities by a factor of 1.6. The phenomenon is caused mainly by high residential consumption in these munici-

palities.

3) All reported waterworks prefer to employ some form of user's charges over general taxation. There are basically two pricing methods widely used throughout the province. These are: metered rates which impose marginal monetary costs on the consumer, and flat rates which are characterized by zero variable price. In a number of Alberta municipalities, the rates are levied on the basis of some factors believed to significantly influence the level of water use. Such a rate is referred to as an assessed flat rate. Virtually all reported metered municipalities use a block meter rate schedule, which includes a graduated minimum rate that increases as the size of the meter increases. In most cases, some base quantity of water is allowed with the minimum bill. Water consumption in excess of this amount is charged at the "commodity" price. The minimum rates, variable rates and, to a certain degree, flat rates per residential account appear to reflect economies of large scale production because they vary with the size of the waterworks.

4) Water sales revenues are the major source of waterworks revenue. General revenue funds, obtained by taxation and other means, are frequently drawn upon to cover waterworks' expenditures. Only the largest Alberta waterworks show an operating surplus and make net contributions to the municipal general revenue fund. It is evident that the industry is characterized by economies of scale where the decline in the expenditure per unit is of the order of 3.7 between the smallest and largest in the province. As water users and municipal taxpayers, in general, urban Albertans pay less for waterworks services in municipalities served by large output waterworks.

5) It was hypothesized that structural relationships exist between average annual residential use by individual residents, the average water-

works pumpage per person served, and a number of "explanatory" variables. The total pumpage and residential water use have been averaged over a period of two years. Both pumpage and residential water use data are not free from errors in measurement. In spite of these errors in the dependent variables, and employing secondary data in the case of some "explanatory" variables, the results of least squares analysis have provided useful information regarding the structural relationship.

In metered municipalities, the pricing policy of allowing some base quantity of water with the base rate tends to increase the level of residential water use per resident. On the other hand, an increase in the base rate may be expected to reduce water demands (the coefficient of price elasticity is -0.28).

When residential customers are subjected to flat or assessed flat rates, any increase in the rate will stimulate water use (the price elasticity is +0.63). This relationship is exactly opposite to that found in metered municipalities, where the size of a bill restrains water use. An increase in affluence of residential customers, as measured by the assessed building and land value, is also positively related to the level of water use (the price elasticity of this term is 0.71).

The analysis of the combined sample of municipalities which differ with respect to pricing methods indicates the impact of the mode of pricing on residential water use. The evidence at hand suggests that the decision to meter residential water would result in reduction in water use and thus may postpone required waterworks expansion or decrease seasonal peak demands.

A similar influence of mode of pricing can be observed when the total pumpage per person served is analyzed. The coefficient of price elasticity (-0.46) indicates a moderate degree of responsivness of all municipal users.

as a group, to changes in water rates. Differences in the moisture deficit have been shown to have small impact on the total (annual) pumpage.

The relatively low explanatory "power" of certain variables, such as moisture deficit, assessed real estate value, and water rate, in the case of an equation estimating residential water consumption is puzzling.

It appears that consumers do adjust their water use levels for differences in wealth, pricing methods, and for higher or lower prices whenever an incentive and an opportunity to do so exists.

6) The provision of adequate water supplies is of public interest. However, the production of treated, piped water is characterized by heavy initial outlays. The problem, then, is to determine which of the price-output combinations, from the social point of view, yields the most effective allocation of resources. Waterworks are "natural" monopolies, and in most cases are owned by the local governments. Thus, price setting is of prime importance. Consideration has been given to the subject of price policy as a device to make better use of existing facilities and as a means to foster better decisions concerning the magnitude and timing of new investment. A multipart pricing schedule has been suggested. Multipart pricing, because of inclusion of marginal cost pricing and an assessed charge, would ensure not only covering all operating costs by price but would also assure the greatest possible compliance with an economically efficient resource allocation.

7) A multiple regression analysis of operating expenditures has clearly demonstrated the presence of economies of scale in the industry. It has also been shown that metering is not a costless alternative and this may be of importance to waterworks managers, especially in the case of abundant water supplies associated with low unit costs. Other things being equal, ground water seems to be less costly to exploit than water

from rivers or reservoirs, apparently because the quality of the intake water influences treatment costs.

The existence of significant economies of scale in the production of quality drinking water places smaller municipalities at a disadvantage. It appears that the consolidation of small output waterworks would be an alternative. The feasibility of consolidating waterworks would depend to a large degree on the location of the communities in relation to a common source of water, as well as on other economic and political factors. Nevertheless, possibilities for taking advantage of economies of scale in water production exist in Alberta as demonstrated by sales of water outside the corporate limits of large output waterworks.

8) The empirical version of the pricing discussion points out that analysis of demands should be made in conjuction with an analysis of the costs of water supply and water pricing policies in order to take account of water user responses to changes in supply costs as these costs are passed on to the municipal user either in the form of a direct price or a tax rate. The form of pricing has been shown to be an important determinant of demand patterns. If resources devoted to provision of water for community usage are to be allocated to provide maximum benefits from their use, consideration has to be given to waterworks price policy.

9) Further research should be undertaken, especially to study the effect of various factors in the case of flat rate pricing municipalities. More consideration should be given to improved pumpage and consumption statistics. There is also room to experiment with other cost forms.

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APPENDICES

APPENDIX I

METRIC CONVERSION TABLE AND APPLICATIONS

METRIC CONVERSION TABLE AND APPLICATIONS

Description	Unit	Symbol	English Equivalent
Volume	cubic meter	m^3	35.315 cubic feet
			219.976 Imperial gallons
			264.172 U.S. gallons
	liter	l	0.035 cubic foot
			0.220 Imperial gallon
			0.264 U.S. gallon
			0.880 Imperial liquid quart
			1.057 U.S. liquid quarts
Flow Rates	cubic meter per year	m^3/yr.	0.603 Imperial gallon per day
			0.724 U.S. gallon per day
	1,000 cubic meters per year	1,000m^3/yr.	0.811 acre-foot per year
			0.001 cubic foot per second

METRIC CONVERSION TABLE AND APPLICATIONS (continued)

Description	Unit	Symbol	English Equivalent
<u>Length</u>	meter	m	39.370 inches
			3.281 feet
			1.093 yards
	millimeter	mm	0.039 inch
<u>Temperature</u>	degree Celsius	^{o}C	1.8 (^{o}C)-32 degrees Farenheit
<u>Prices</u>	\$ 100 per cubic meter		\$ 2.83 per cubic foot
			\$ 0.455 per Imperial gallon
			\$ 0.379 per U.S. gallon

APPENDIX II

TABULATION OF REVENUE AND EXPENDITURE DATA PER

PERSON BY: SIZE OF WATERWORKS

POPULATION SIZE

PRIMARY SOURCE OF WATER

TABLE 1

REVENUE AND EXPENDITURE PER PERSON, BY SIZE OF WATERWORKS, ALBERTA, 1966

Size of Waterworks	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
Gross Pumpage >1 mil. m^3/yr.	8	14.43	3.76	18.19	17.33	0.86	0.94	1.80
Gross Pumpage >100,000 m^3/yr.	57	17.82	1.53	19.35	22.25	-2.90	4.32	1.42
Gross Pumpage <100,000 m^3/yr.	84	18.94	0.65	19.59	28.89	-9.30	10.05	0.75
Waterworks Reporting	149	18.27	1.15	19.42	25.73	6.31	7.32	1.01

TABLE 2

REVENUE AND EXPENDITURE PER PERSON, BY SIZE OF WATERWORKS, ALBERTA, 1967

Size of Waterworks	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
Gross Pumpage $\geq$1 mil. m^3/yr.	8	16.15	2.66	18.81	18.39	0.42	0.93	1.35
Gross Pumpage >100,000 m^3/yr.	57	19.57	1.19	20.76	23.24	-2.48	4.25	1.77
Gross Pumpage $\leq$100,000 m^3/yr.	84	19.70	0.53	20.23	30.79	-10.56	9.76	-0.80
Waterworks Reporting	149	19.46	0.90	20.36	27.24	-6.88	7.13	-0.25

TABLE 3

REVENUE AND EXPENDITURE PER PERSON, BY POPULATION SIZE, ALBERTA, 1966

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
>100,000	2	14.13	2.39	16.52	11.93	4.59	-1.49	3.10
10,001-100,000	4	13.08	5.91	18.99	18.85	0.14	1.67	1.81
3,001-10,000	15	15.22	1.65	16.87	18.07	-1.20	2.67	1.47
1,001-3,000	47	17.97	1.36	19.33	21.65	-2.32	3.77	1.45
501-1,000	40	17.72	0.98	18.70	23.89	-5.19	6.82	1.63
<500	96	19.38	0.61	19.99	30.72	-10.73	11.37	-0.65
Waterworks Reporting	204	18.25	1.06	19.31	25.94	-6.63	7.66	1.03

TABLE 4

REVENUE AND EXPENDITURE PER PERSON, BY POPULATION SIZE, ALBERTA, 1967

Population Size	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
>100,000	2	14.88	2.35	17.23	11.15	6.08	-1.66	4.42
10,001-100,000	4	15.99	3.47	19.46	19.43	0.03	1.73	1.76
3,001-10,000	15	17.15	1.56	18.71	19.42	-0.71	2.46	1.75
1,001-3,000	47	19.46	0.93	20.39	23.46	-3.07	4.25	1.18
501-1,000	40	18.70	0.66	19.36	25.06	-5.70	6.37	-0.67
<500	96	20.31	0.51	20.82	33.11	-12.29	10.96	-1.33
Waterworks Reporting	204	19.43	0.79	20.22	27.81	-7.59	7.48	-0.11

TABLE 5

REVENUE AND EXPENDITURE PER PERSON, BY PRIMARY SOURCE OF WATER, ALBERTA, 1966

Primary Source of Water	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
Wells	113	17.42	0.71	18.13	24.53	-6.40	8.15	1.75
Rivers	41	19.56	2.24	21.80	25.26	-3.46	4.71	1.25
Irrigation System	20	18.34	0.62	18.96	25.40	-6.44	9.23	2.79
Reservoirs	14	19.14	1.41	20.55	34.66	-14.11	9.36	-4.75
Lakes	11	17.92	0.12	18.04	25.06	-7.02	8.01	0.99
Other	5	23.09	1.21	24.30	32.19	-7.89	8.44	-0.55
Waterworks Reporting	204	18.25	1.06	19.31	25.94	-6.63	7.66	1.03

TABLE 6

REVENUE AND EXPENDITURE PER PERSON, BY PRIMARY SOURCE OF WATER, ALBERTA, 1967

Primary Source of Water	Waterworks Reporting	Sales Revenue	Other Revenue	Operating Revenue	Expenditure	Operating Surplus or Deficit (-)	Net Transfers from General Revenue Fund	Total Surplus or Deficit (-)
		Dollars per Person per Year						
Wells	113	18.13	0.54	18.67	25.88	-7.21	7.94	0.73
Rivers	41	21.48	1.41	22.89	27.01	-4.12	4.65	0.53
Irrigation System	20	20.45	0.44	20.89	29.40	-8.50	9.39	-0.89
Reservoirs	14	21.22	1.56	22.78	36.43	-13.65	9.20	-4.45
Lakes	11	18.71	0.16	18.87	30.25	-11.38	8.34	-3.04
Other	5	23.52	0.73	24.25	33.94	-9.69	5.86	-3.83
Waterworks Reporting	204	19.43	0.79	20.22	27.81	-7.59	7.48	-0.11

APPENDIX III

SELECTED ESTIMATING EQUATIONS FOR:

RESIDENTIAL WATER USE IN METERED MUNICIPALITIES

TOTAL PUMPAGE IN METERED MUNICIPALITIES

TABLE 1

SELECTED ESTIMATING EQUATIONS FOR RESIDENTIAL WATER USE

AND TOTAL PUMPAGE IN METERED MUNICIPALITIES, ALBERTA, 1966-1967

A. Residential Water Use per Resident per Year: $RU_r = f(A_p, BQ, BR, HS, PD, MR)$

(1) $$RU_r = 154.823^{**} - 0.406BR + 0.143BQ^{**} - 19.783HS^{*} + 0.265PD - 1.179A_p$$

	Constant	BR	BQ	HS	PD	A_p
standard errors:	18.064	0.451	0.049	10.854	0.515	9.188
elasticity coefficients:		-0.205	+0.287	-0.967	+0.114	-0.023

$R^2 = 0.43$ F-value = 3.23^{*} N = 27

(2) $$RU_r = 153.620^{**} - 0.386BR + 0.140BQ^{**} - 20.053HS^{*} + 0.263PD$$

	Constant	BR	BQ	HS	PD
standard errors:	17.656	0.416	0.043	10.407	0.503
elasticity coefficients:		-0.195	+0.281	-0.980	+0.114

TABLE 1 (continued)

$R^2 = 0.43$ F-value $= 4.2^*$ $N = 27$

(3) $$RU_r = 79.390 + 0.690MR^* + 0.53PD^o - 1.945A_p$$

standard errors:	20.200	0.371	0.294	5.241
elasticity coefficients:		+0.219	+0.231	-0.026

$R^2 = 0.23$ F-value $= 2.2$ $N = 27$

(4) $$\log RU_r = 2.3261^{**} - 0.778 \log HS^* - 0.323 \log BR^{**} + 0.231 \log BQ^{**}$$

standard errors:	0.1003	0.479	0.120	0.087

Note: The regression coefficients also represent elasticity coefficients because of the multiplicative nature of the equation.

$R^2 = 0.32$ F-value $= 3.63^*$ $N = 27$

TABLE 1 (continued)

B. Total Pumpage per Person per Year: $TP_p = f(A_p, BQ, BR, HS, MR)$

(5) $$TP_p = 192.291^{**} + 0.202BQ^{**} - 35.963HS^{**} + 17.132A_p{}^{o} - 0.61MR$$

standard errors:	24.801	0.068	13.940	11.231	0.489
elasticity coefficients:		+ 0.311	-1.349	+0.261	0.146

$R^2 = 0.47$ F-value = 4.59^{**} N = 26

(6) $$TP_p = 158.860^{**} + 0.180BQ^{**} - 26.960HS^{*} + 16.410A_p - 0.280BR$$

standard errors:	25.460	0.070	14.860	13.040	0.043
elasticity coefficients:		+0.277	-1.011	+0.251	-0.110

$R^2 = 0.44$ F-value = 4.08^{*} N = 26

TABLE 1 (continued)

(7) $$TP_p = 158.446^{**} + 0.163BQ^{**} - 30.748HS^{**} + 20.819A_p^{*}$$

standard errors:	25.126	0.061	13.482	10.982
elasticity coefficients:		+0.251	-1.153	+0.318

$R^2 = 0.43$ F-value = 5.4^{**} N = 26

Notes: A_p is the assessed value of land and buildings in thousands of dollars per person (2 year average).

BQ is the base quantity of water in cubic meters per residential account per year that is allowed with the base rate.

BR is the base rate in dollars per residential account per year.

HS is the household size.

PD is the precipitation deficit in millimeters for May - September period (2 year average).

MR is the marginal rate in cents applicable in first block.

RU_r is the residential water use in cubic meters per person per year (2 year average).

TP_p is the total pumpage per person in cubic meters per year (2 year average).

o significant at 90 - 95 percent level
* significant at 95 - 99 percent level
** significant at > 99 percent level